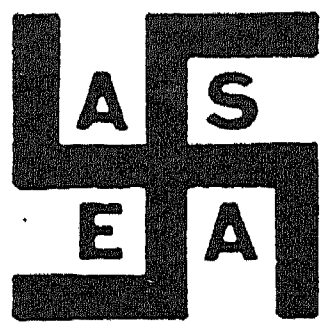


ASEA-JOURNAL

ALLMANNA SVENSKA
ELEKTRISKA A.B.
WESTERAS — SWEDEN



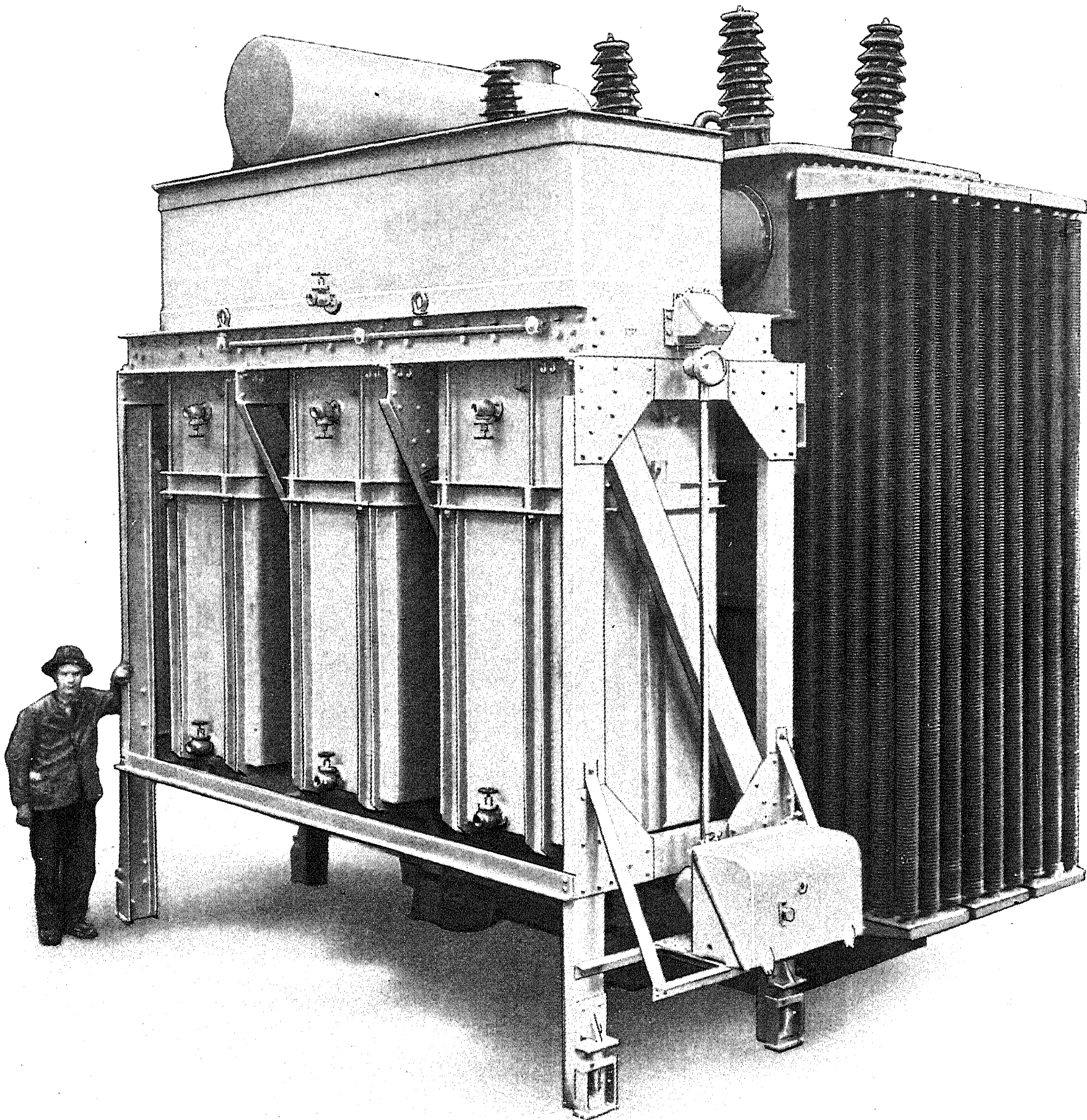
ASEA ELECTRIC LTD
5, CHANCERY LANE — LONDON

MONTHLY REVIEW

VOL. VIII
1931

All correspondence should be addressed to the Editor, Publicity Dept.
Asea, Westeras, Sweden.
Permission is given to reprint articles or extracts from this journal,
on condition that the name — Asea-Journal — is clearly stated.

MARCH
No. 3



12500 kVA self cooled three-phase transformer $70000 \pm 2 \pm 4 \pm 6 \pm 8 \pm 10$ %/6500 volts, 50 cycles, with motor operated on-load ratio regulator combined with the transformer.

ASEA ELECTRIC LTD.

FELTHAM HOUSE,
GRAHAM ROAD,
BOMBAY.

SASSOON HOUSE,
4, LYONS RANGE,
CALCUTTA.

VOLTAGE REGULATING ARRANGEMENTS FOR TRANSFORMERS.

BY E. STENKVIST.

Summary.

This subject has been handled previously in the Asea Journal, September 1924, but since that date so many improvements have been introduced, that a completely new description is now considered to be of interest. The first part of the article deals with the principal points which should be considered in the general arrangement of tapplings on transformer windings in order to avoid excessive short circuit stresses when the range of regulation is large, and heavy eddy current losses caused by radial leakage fields, which in general have to be reckoned with, due to unsymmetrical winding arrangements when tapplings are provided. The latter part of the article deals with contructional details by which tapplings are made available for reconnection. For reconnection under no-load conditions a connection board under the cover, multi-pole leading through bushings or tapping switches can be used, and these are described together with precautions which have to be taken to ensure the reliability of such apparatus. During the last few years a class of apparatus known as ratio regulators has been generally employed by Asea for reconnecting transformers on load. Such apparatus has been manufactured by Asea for a long time, and some historical notes on development are given after which the article is concluded by a short description of Asea's present day designs in this field.

*

For a good many years it has been quite usual to provide transformers with regulating tapplings on one or both windings. The steady increase in the magnitude of loads and supply systems is making the question of voltage regulation one of the greatest possible importance, and

point out the features which should be specially considered in determining their suitability in different cases.

For the past ten years there has been a general opinion that extra tapplings are a likely source of trouble and are better eliminated altogether if possible, when a reliable transformer is required. It can now be said quite definitely that development during the past few years has got beyond this stage. The unfortunate experiences of earlier times may be attributed to the fact that definite knowledge was wanting regarding certain parts of transformer theory, vital in this special connection, viz. information as to the production and action of radial leakage fields. It is to be noted that to-day the available literature handles this question in a very haphazard manner which is much to be deplored, since it is one of primary importance to the designer. In approaching the problem difficulties are immediately encountered, since the path of the leakage field is to a great degree affected by mechanical constructional details, such as press flanges and tanks, and by the flux density in various iron parts which help to make up the magnetic circuit. The problem cannot be subjected to an exact mathematical treatment. An earlier article in this Journal for September 1924, gave an elementary exposition of the problem which, without pretending to be accurate to any very high degree, was calculated to throw some light upon the effect of the derangement of the symmetry of windings which is usually caused

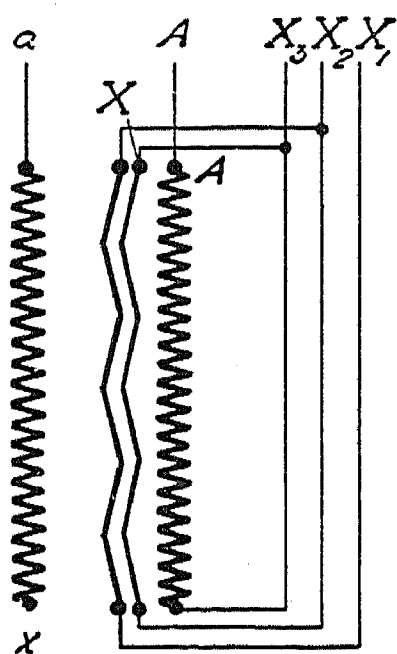
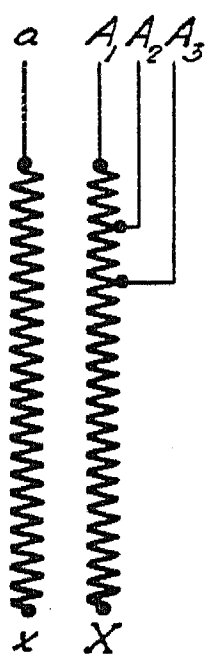
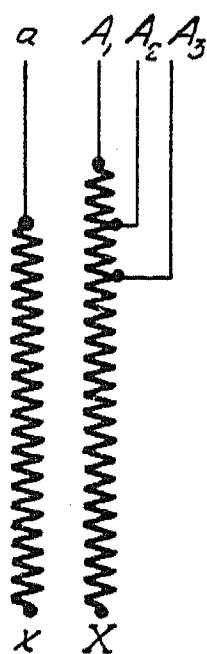


Fig. 1.



a



b

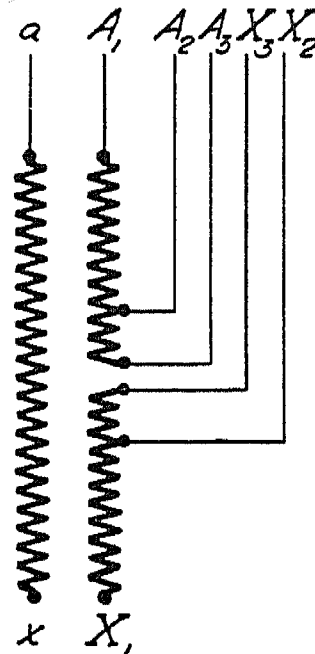


Fig. 3.

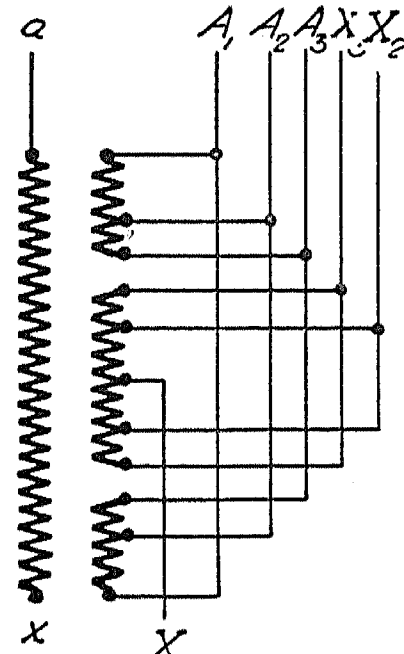


Fig. 4.

the suitable arrangement of ratio changing devices on transformers has latterly become a matter of great moment, and often a determining factor in transformer construction. During the last few years particularly, much investigation has been carried out in this direction, and it is desirable to present a brief review of the designs and constructions now available, and to

by introducing additional tapplings. This treatment related throughout to the type of transformer which is still the standard manufactured in Sweden, and in most other countries, viz. the core type transformer with cylindrical windings. The theory submitted shewed that there is only one way of entirely avoiding dissymmetry in the axial direction when making connections to

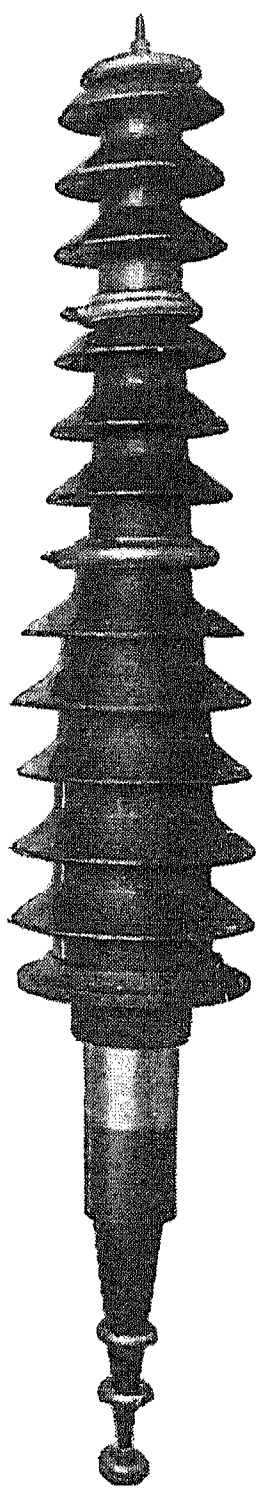


Fig. 5. Three-pole condenser type leading through bushing for 66 kV working pressure, outdoor pattern.

any of the extra tapplings. This is to design the winding in accordance with the diagram reproduced in *fig. 1*, in which case, when changing from one ratio to another, a complete layer of the windings extending the whole length of the main winding is connected or disconnected. This arrangement is ideal from the point of view of symmetry, and should accordingly be used whenever possible. Unfortunately the use of this arrangement is limited for several reasons. It is clear that between points A and X in the diagram the whole phase voltage exists, so that this must not be exceptionally high, if we are to avoid carrying out the insulation between the main and regulating windings on the principals which are applied to the insulation between the H.T. and L.T. windings *i.e.* by means of oil ducts divided by one or more bakelite cylinders. The double wound transformer thus becomes in the mechanical respect a treble wound transformer, and for this reason it will be clear that an arrangement in accordance with *fig. 1* is usually relatively expensive, and will not be acceptable to a customer who judges a transformer exclusively by price and guaranteed losses.

It may further be noted that when the regulating steps are small, the thickness of each layer in the regulating winding also becomes very small. If the step is 5 % the thickness of the layer will be approximately 5 % of the thickness of the main winding *i.e.* something of the order of 1.5 to 4 mm. One method of avoiding such dimensions, which are unsatisfactory in the mechanical respect, is naturally to disregard the question of economical current densities, and to take such a heavy copper section for the winding that mechanically acceptable dimensions will be secured for the regulating winding, but this makes the construction still more expensive. This method is, however, employed by Asea to a large extent, although with a number of modifications particularly when large and heavy units are in question. In the case of windings for which the pressure is low in relation to the output a further limit is imposed, since the main winding, which is dependent on the necessary core section, must have relatively few turns. Something like 100 turns for a normal L.T. winding is very common. If in such a case a regulating step of 2 % is required it is clear that the principal outlined

above cannot be applied, since it would be impossible to distribute the two turns necessary for the regulating winding in a satisfactory manner along a winding having a length of from 1 to 2 metres.

It is thus apparent that in many cases we must resort to earlier practice, and connect regulating tapplings directly to the main winding, although dissymmetry cannot then be avoided. Unless these tapplings are arranged with the greatest possible care it is quite easy to obtain a design which must be condemned at once, since short circuit stresses may occur, which the transformer cannot withstand. It does not help us to introduce clamping arrangements, however strong these may be, since the windings themselves can only be subjected to a more or less limited stress. On the other hand definite improvements can be obtained by relatively simple means, and in effecting these, it is only necessary to keep the dissymmetry in the axial direction as small as possible. The least one can do when disconnecting turns from one end of a winding is thus not to design the windings of equal height as in *fig. 2 a* but so that symmetry is obtained about a centre tapping as in *fig. 2 b*.

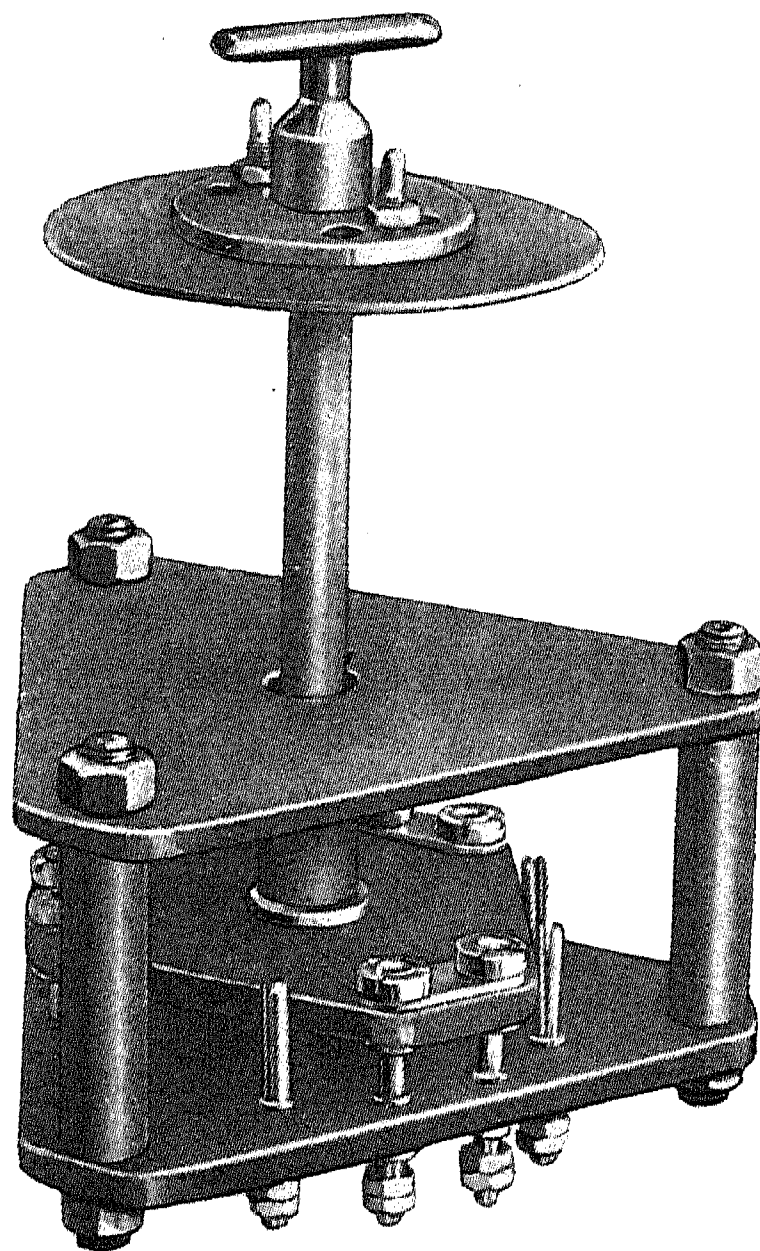


Fig. 6. Off-load tapping switch with operating device, smaller type.

In this way the maximum dissymmetry occurring between the windings is reduced to a half. Such an arrangement of the windings is, however, considered by Asea, and doubtless by most other firms to be too primitive, and is not now employed. The location of tapplings at the centre of the winding, however, provides an accept-

able arrangement in many cases (*fig. 3*). Dissymmetry is thus again reduced by a half. It might be thought that this system could be extended and applied to all cases which might occur. The next step would be to arrange the

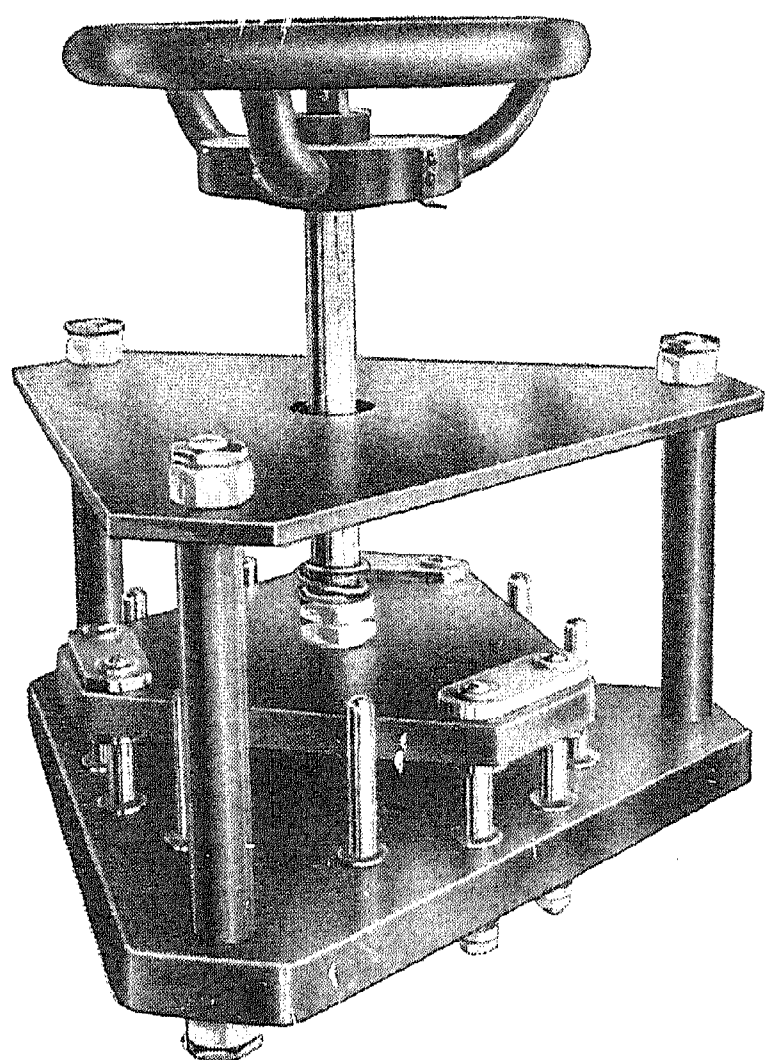


Fig. 7. Off-load tapping switch with handwheel, larger type.

windings in accordance with the scheme in *fig. 4*, where the winding is divided into two parallel connected groups with regulating tappings located in the middle of each group, enabling, the dissymmetry to be halved once more. Naturally one can proceed in this way and design the winding in several parallel connected groups, making it possible to deal with much larger ranges of regulation. The additional price for such an arrangement would, however, become more serious. A division of the winding into two parallel groups means that the space required by the winding becomes approximately the same as for a transformer with a working voltage double as great. The point is that the transformer can be built for any regulation, as large as may be desired, but that this can only be secured at a very considerably increased price if dissymmetry is to be kept within allowable limits.

We must now examine the methods by which regulating tappings can be made available for reconnection. The oldest and at the same time the simplest and cheapest method is to bring up connections from the tappings to a plug or terminal board mounted over the upper yoke of the transformer and not to bring them through the cover at all. In most cases, however, this arrangement must be regarded as very unsuitable, and this is particularly so when transformers are provided with leading through bush-

ings on the cover, a construction which is practically standard with all European firms. Such a transformer must be designed with the cover rigidly connected to the core, since the leads inside cannot be taken off the leading through bushings beneath the cover when the transformer is to be lifted out of the tank. We are, therefore, obliged to lift the cover with the leading through bushings, terminals connections and core together as a single unit. We may remark in parenthesis that this is a great advantage, since the transformer can be raised for inspection without breaking any internal connections. Lifting in this way must, however, be undertaken every time the tappings are to be altered, and this may become exceedingly troublesome. It is only necessary to consider as an example, an outdoor transformer mounted on poles, or a large power transformer erected in some position where no crane is available. It may be the case that on account of such difficulties the reconnection of such a transformer will seldom or never be undertaken, and this is sufficient to condemn the design. For this reason it is often specified that the reconnection board for the extra tappings shall be placed immediately under the cover and accessible through a manhole. As three-phase transformers are in general supplied with seven leading through bushings on the cover it will be clear that there is very little space available, at any rate in the case of small units, for a manhole or handhole of adequate size. This construction may now be considered quite obsolete, since it is possible to instal a tapping switch which can be operated from outside the transformer at considerably

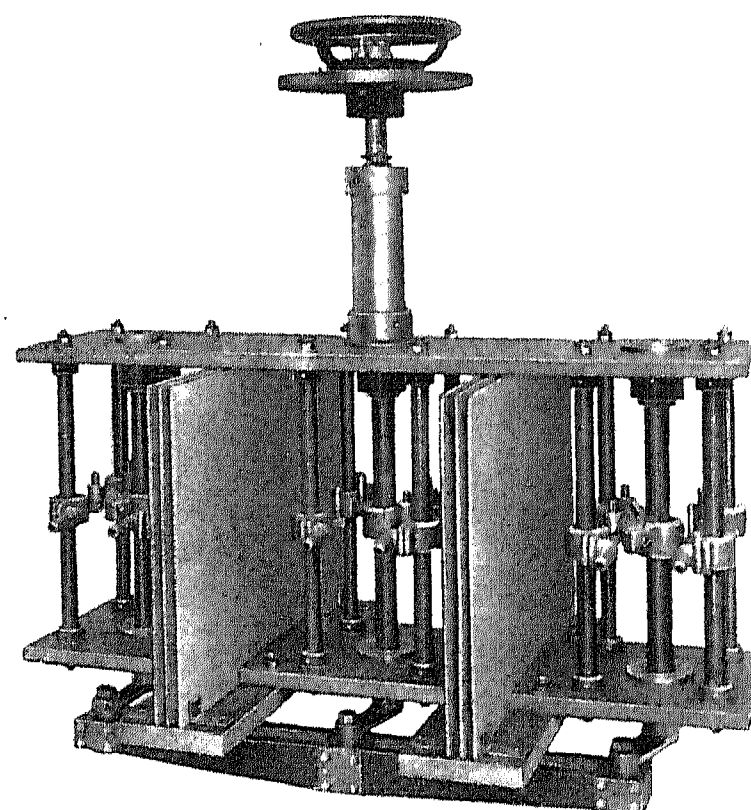


Fig. 8. Off-load tapping switch with three positions, 70 kV working pressure.

lower cost than would be involved by the provision of a connecting board and manhole. Such an arrangement is, of course, also very much easier to operate. If, however, a transformer is arranged in accordance with American practice

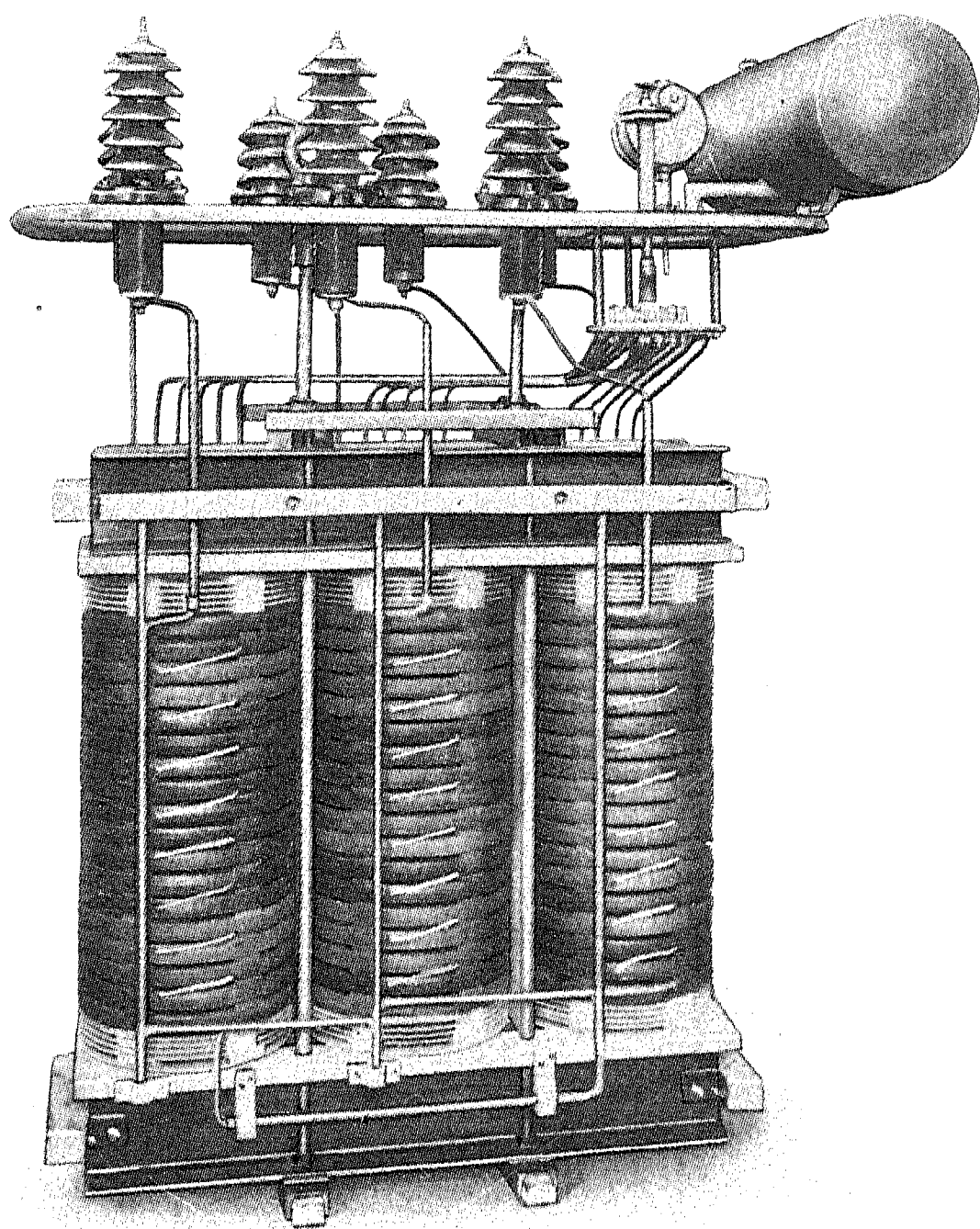


Fig. 9. 250 kVA three-phase transformer with off-load tapping switch.

with a cover which is separately removable, the conditions are different, as will be found mentioned in a previous description in this Journal of the Asea Transformer Types TZ and EZ which are designed in this way.

Returning to transformers having leading through bushings on the cover it was soon found that the above mentioned primitive arrangement with extra tapplings located under the cover must be improved upon, and on this account transformers were manufactured for a long time with tapplings brought through the cover by means of additional bushings so that the reconnection could be made from outside. For small transformers and also for large transformers designed for high working voltages, sufficient space is wanting on the cover for the provision of a bushing for each voltage required. It was therefore found necessary to develop leading through bushings of a special kind enabling several tapplings to be brought out through the same bushing. After experimenting with a number of different designs, these bushings are in general manufactured with a central bolt surrounded by several concentric copper tubes insulated from it and from one another.

It is clear that the introduction of these bushings mark a considerable improvement, but the arrangement can scarcely be regarded as ideal. One of the chief disadvantages is the high cost. In order that a multi-pole leading through bush-

ing may be reliable, the manufacture must be carried out with extreme care.

As an example it can be mentioned that for high voltages it has been found necessary by Asea to introduce between the bolt and concentric tubes insulation arranged on the same principal as that used for ordinary condenser type leading through bushings. A three-pole leading through bushing is thus built up of three separate and concentric condenser bodies. To protect the insulation against damp the main bushing and also the projecting parts of the extra conductors must each be enclosed by porcelain shells and the space between the porcelain and bakelite bodies has to be filled with compound. This construction is used both in indoor and outdoor bushings and at the present time such leading through bushings are manufactured with a maximum of three tapplings and for working voltages up to a maximum of 88 kV. Fig. 5 shows an example of such a bushing for a working voltage of 66 kV. It is clear that the cost of this arrangement must be excessive, and this disadvantage is all the more marked, since it is desirable that the extra tapplings should not be adjacent to the main terminal, but at the centre point of the winding, in which case the voltage difference between them and the main terminal necessitates the use of one or more separate sets of bushings for the regulating tap-

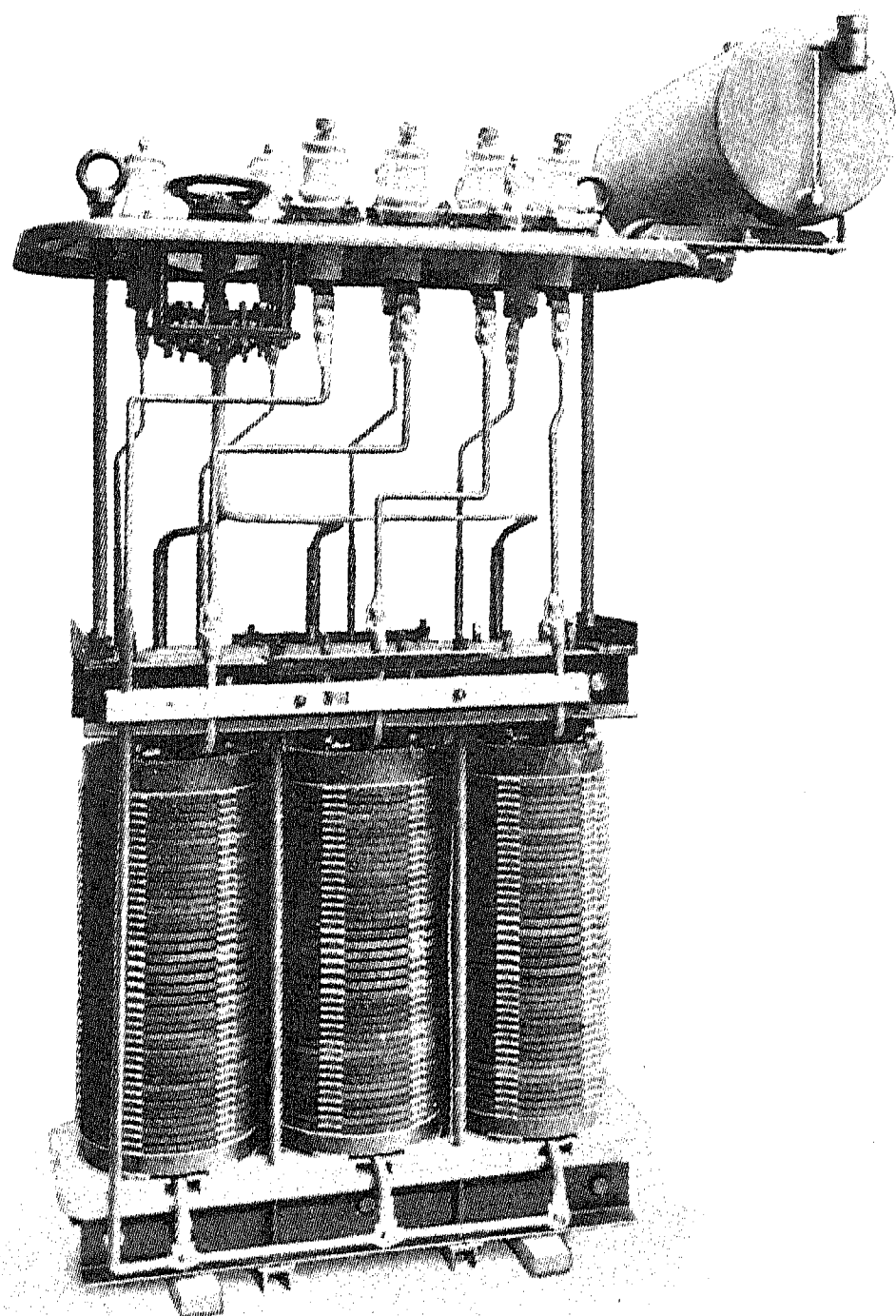


Fig. 10. 300 kVA three-phase transformer with off-load tapping switch.

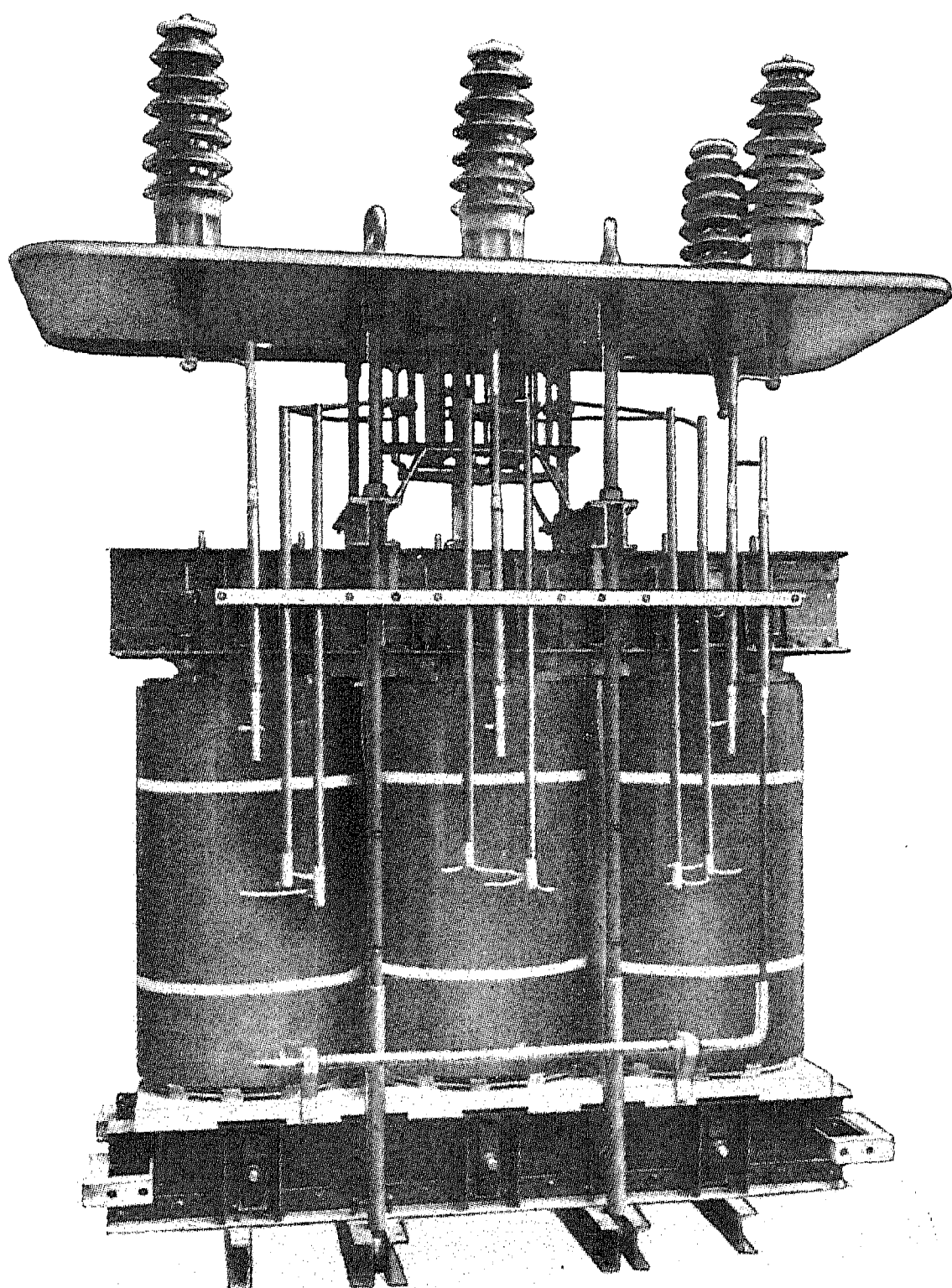


Fig. 11. 6000 kVA three-phase transformer $70000 \pm 5\%$ /6300 volts, furnished with off-load tapping switch.

pings. It should further be mentioned as a point against this design that incorrect connections may easily be made.

Tapping switches.

The multi-pole leading through bushings described above which were widely employed a few years ago, are now to a great degree superseded by tapping switches. By tapping switch is meant an apparatus mounted inside the transformer tank, and to which the extra tappings

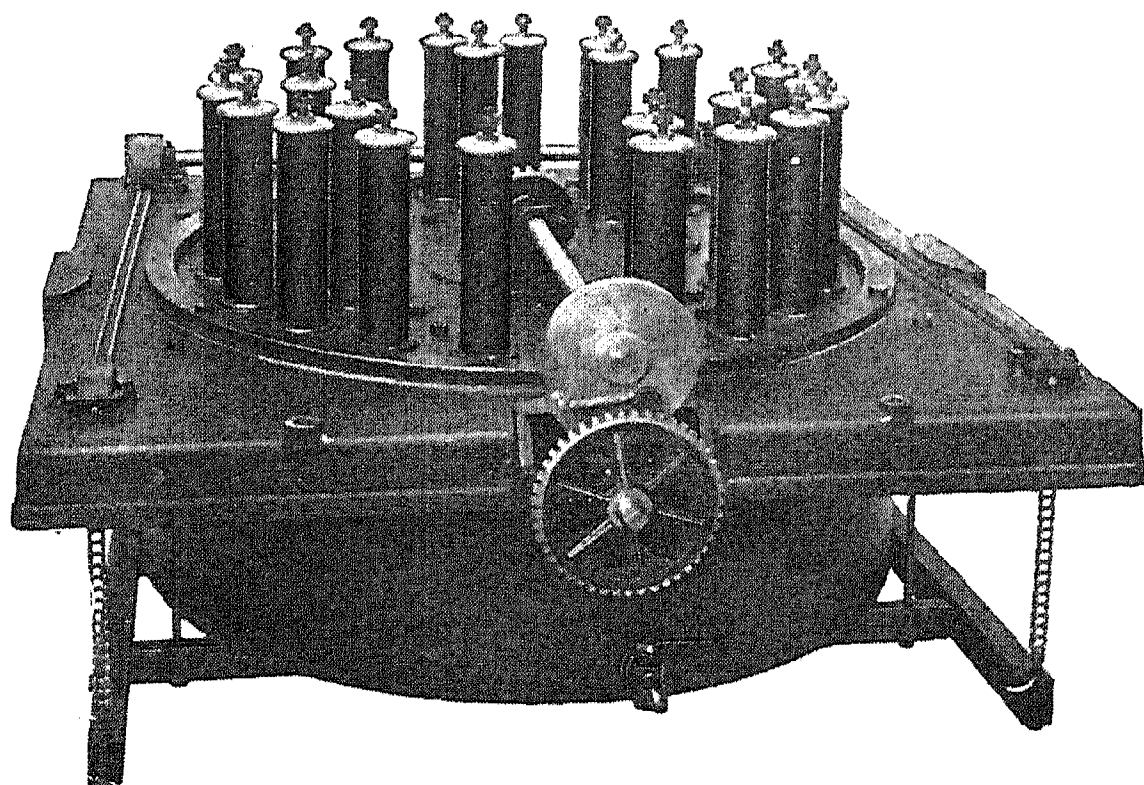


Fig. 12. Earlier type of on-load ratio regulator, 22 kV, 200 amps, six steps.

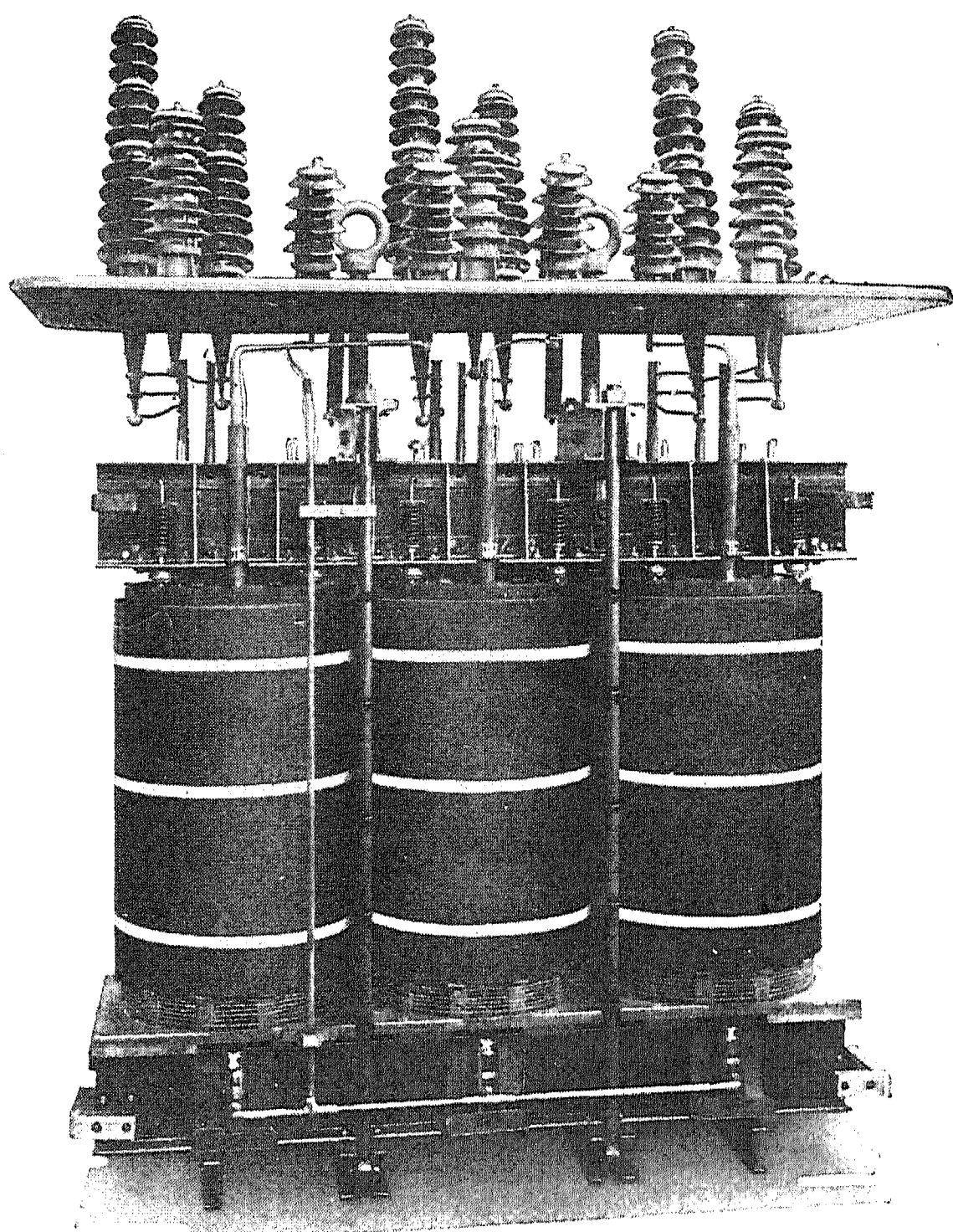


Fig. 13. 6000 kVA three-phase transformer 46/61—58—55—52—49 kV, 50 cycles, outdoor pattern, with multi-pole leading through bushings for connection to separate on-load ratio regulator.

are connected and furnished with an operating device above the cover by means of which the reconnection for different voltages can be effected from outside without otherwise interfering in any way with the transformer or disconnecting leads from the terminal bushings. Reconnection is only made when the transformer is not alive.

Such an apparatus, in spite of being of a simple nature nevertheless presents a somewhat difficult problem to the designer on account of the many requirements which must be met. These are briefly as follows:

1. It must be impossible to make incorrect connections.
2. The contact positions must be clearly indicated.
3. It must be impossible to leave the tapping switch in any mid position.
4. The contacts must be able to carry the maximum short circuit current which can occur.
5. The insulation must be good.

The apparatus introduced by Asea which complies with all the above conditions is manufactured in two forms viz. for connection in the neutral point of Y- or Z-connected windings, and for connection at the centre of Y- or D-connected windings, *fig. 6*. The tapping switch is normally manufactured three-phase for simultaneous reconnection of the three phases

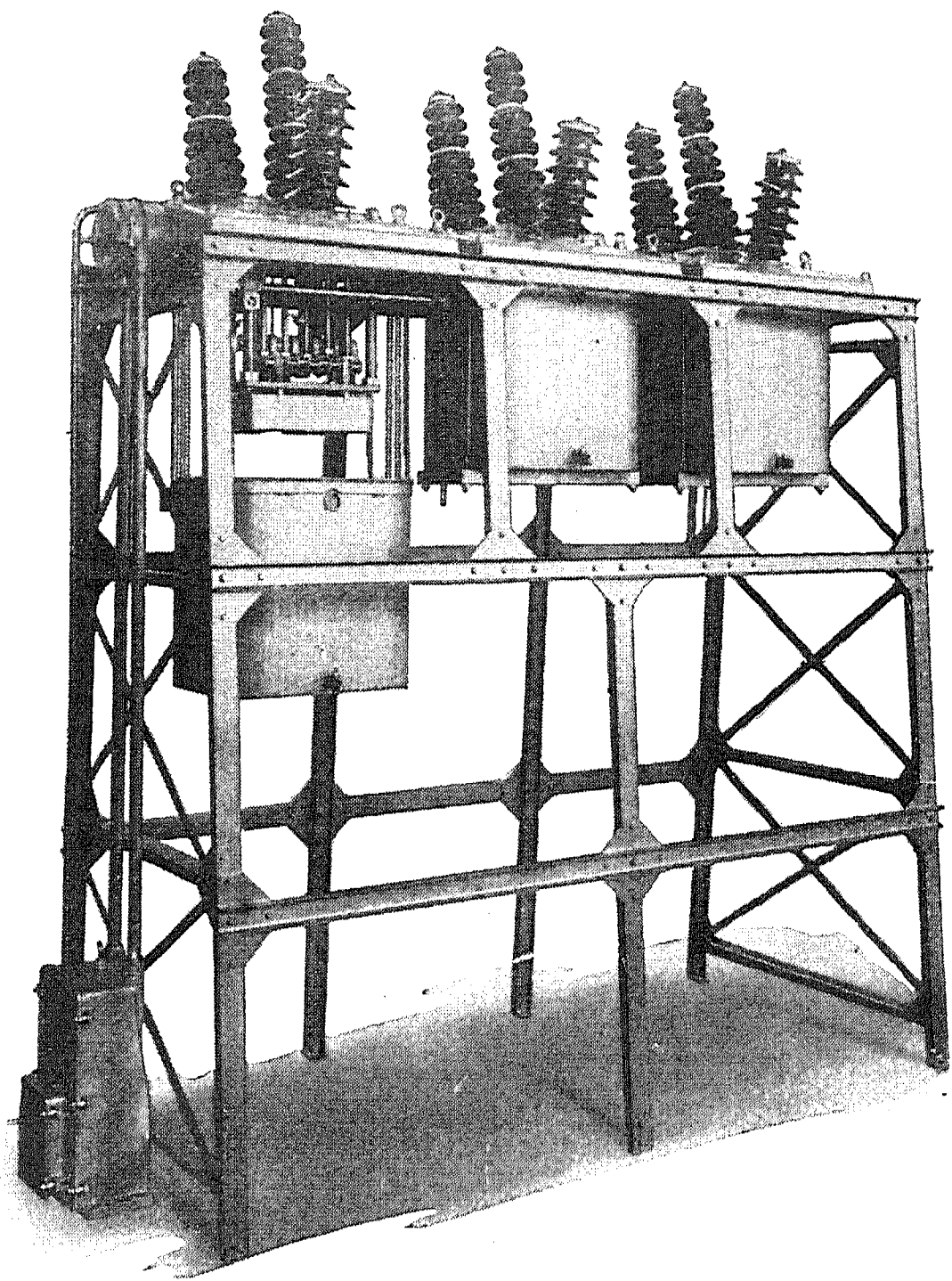


Fig. 14. On-load ratio regulator for the 6000 kVA three-phase transformer in fig. 13, outdoor pattern.

except for apparatus used on voltages above 77 kV, which are only constructed single-phase. The tapping switches consist of a number of contact pins fixed to a common insulating base of special non-hygroscopic material. The material used for this base is homogeneous and has no

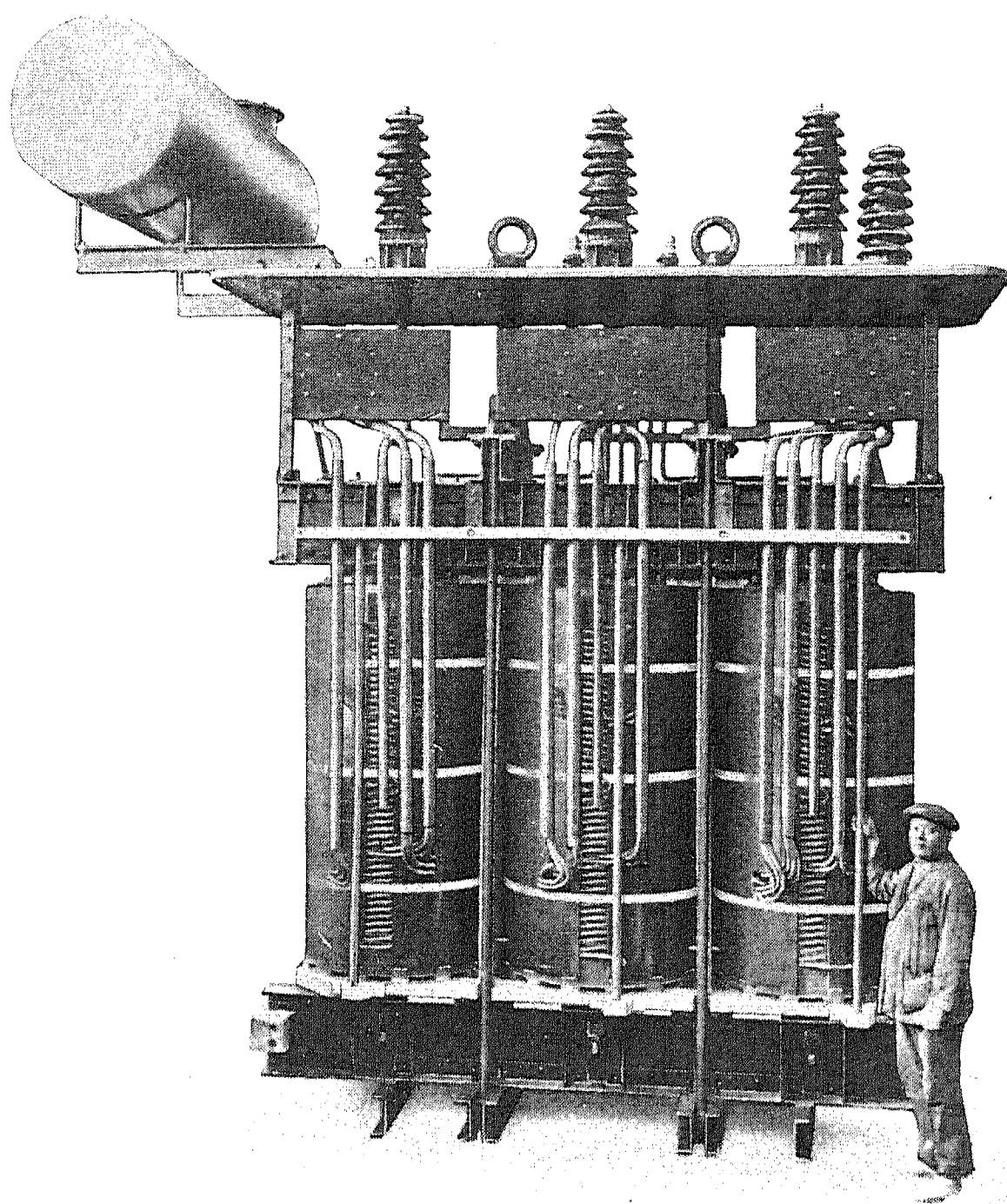


Fig. 16. Interior of 12500 kVA transformer, three-phase $70000 \pm 2 \pm 4 \pm 6 \pm 8 \pm 10$ %/6500 volts, 50 cycles, with tapping connections carried up to bakelite connection boards. The transformer is intended for combination with on-load ratio regulator as shown in the illustration on the front page.

grain in the longitudinal direction. Over the above is arranged a second similar insulating plate having contact sockets, by means of which the pins in each phase can be coupled together in pairs. For this purpose the latter plate which is of the same insulating material, is so fixed that it can be rotated by means of an operating rod which is also manufactured from insulating material in order further to improve the insulation to earth. Above the cover the operating rod is securely connected to a handwheel provided with a disc having holes, the number and position of which correspond to the desired positions of the contacts. By introducing guide pins into these holes the operating handwheel above the cover can be set in a position corresponding exactly to the alignment of the contacts below. The guide pins are threaded and furnished with nuts by means of which the tapping switch can be locked, while tightening up these nuts also serves to compress the packing and makes the device completely oil tight.

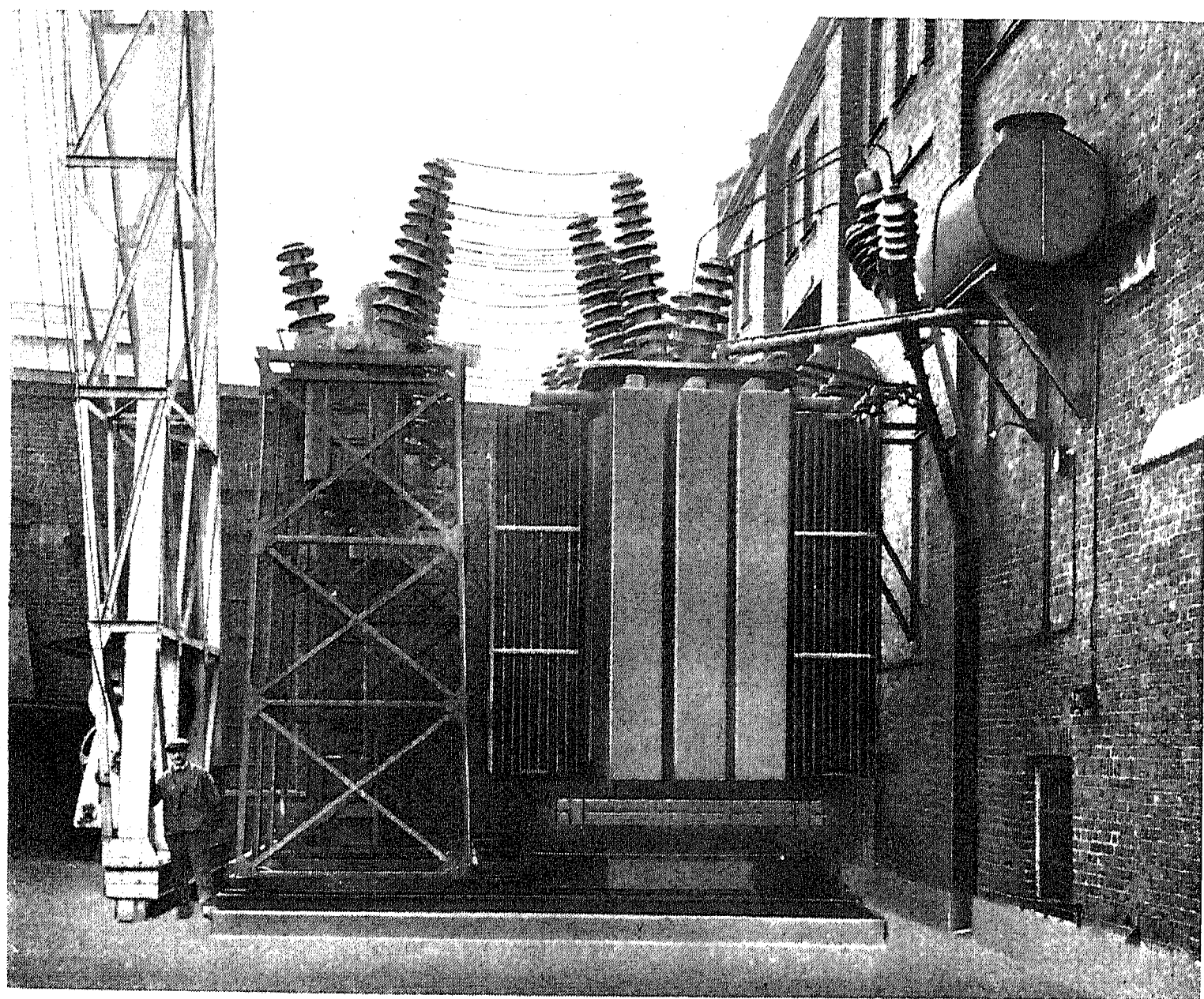
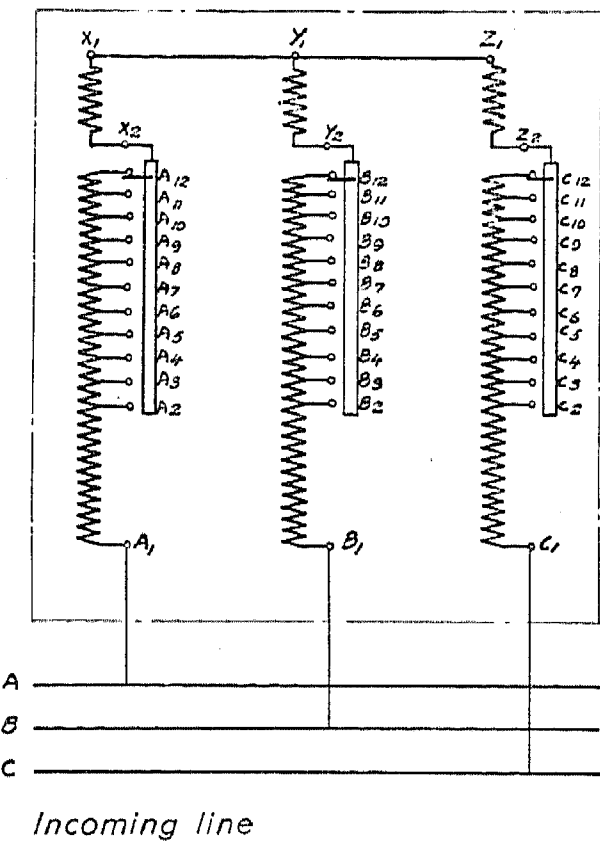


Fig. 15. 12000 kVA three-phase transformer 56.5—54—51.5—49—46.5/5.6 kV, 50 cycles, with separate on load ratio regulator erected out of doors.

To operate the switch the nuts are removed after which the operating rod must be drawn vertically upwards. As the guide pins are longer than the contact pins it is impossible to turn the operating rod before the plug contacts are free of the contact pins. On rotating the handwheel it is clearly impossible to depress the operating rod before the guide pins are opposite the next set of holes in the guide disc. The correct positions accordingly could not possibly be more definitely indicated. In the intermediate positions the contact is broken. If the transformer is provided with an expansion vessel a stuffing gland, through which the rod passes, is welded to the cover, to prevent leakage of oil past the rod. In this way it is not necessary to run any oil out of the transformer or expansion vessel when the tapping switch is to be operated. With small transformers the same result is obtained by arranging the operating handle above the level of the oil in the expansion vessel (*Fig. 9*).

Diagram of connections



As regards insulation all tapping switches fulfil the following conditions. The flashover voltage between adjacent contact pins is as a minimum equal to the working voltage (main voltage). The flashover voltage to earth is the same as the flashover voltage for the terminal bushings. In three-phase tapping switches for reconnection in the centre of the winding

the flashover voltage between contact pins belonging to different phases is as a minimum equal to the test voltage of the winding. To illustrate the ability of these tapping switches to carry overloads, the following particulars may be given which are extracted from the test report on a standard neutral point tapping switch taken at random from stock and designed for a normal current of 60 amps. maximum. The temperature rise was measured by means of thermo elements applied to the apparatus immersed in oil. It was found that the temperature rise above the oil measured at the contact pins was lower than the temperature rise measured at the nuts of the terminals, viz. 2.5° and 3.8°C with normal current. Further the temperature rise was measured at the contact pins after a number of reconnections between two positions and the following results were obtained:

At commencement of test	2.4°
After 1000 reconnections	2.2°
After 3000 reconnections	2.1°
After 20000 reconnections	2.0°

The contacts were accordingly improved by wear.

The following load test was carried out.

A current of 500 amps. was passed from one contact pin through the sockets and contact piece to a second pin for a period of 5 seconds. After the tapping switch had cooled 1000 amps. were passed for 5 seconds, and the tapping switch again allowed to cool. In similar manner the current was increased by 500 amps. each time for periods of 5 seconds. After each load period the contacts were carefully examined for burns and damage. When the load had been increased to 3500 amps. no burns could be detected, but when increasing the current to 4000 amps. the contact pins burnt off close to the plugs with a current between 3500 and 4000 amps. (From this it would appear that the melting commenced from inside while the outer surface remained good up to the very end, and was not burnt on account of the good cooling provided.)

Tapping switches are manufactured for pressures up to a maximum of 132 kV for both Y- and D-connected windings, normally with three positions and with five positions as a maximum.

The apparatus described above simplifies tap changing to a great degree, but the reconnection must be carried out with the transformer

Detailed diagram for linear regulation

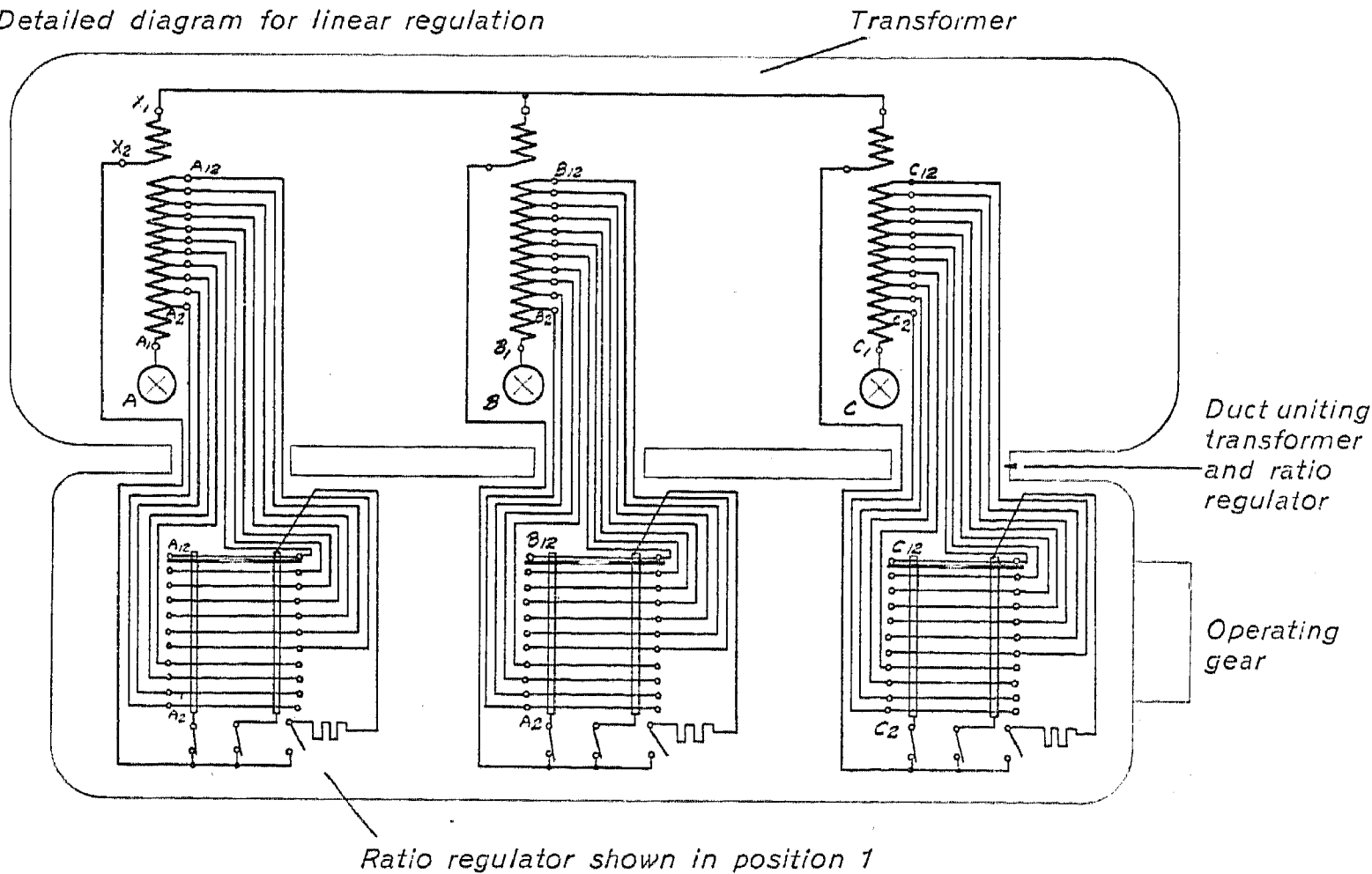


Fig. 17. Diagram of connections for transformer and on-load ratio regulator, linear regulation.

dead. In many cases it is impossible to take a transformer out of service during any part of the twentyfour hours, even for a few minutes, without serious inconvenience. When this is the case or more generally when it is necessary to follow the voltage variation on a supply network continuously the method is much less suitable. Such transformers must be provided with some arrangement allowing for voltage regulation under load.

On-load ratio regulator.

Tap changing under load can be effected by means of special apparatus designated by Asea ratio regulator. It may be pointed out to start with that Asea took up the manufacture of this type of apparatus as early as 1905, and such ratio regulators were used for various purposes including electric furnace installations for the regulation of pressure and loading during service. This commencement has proved very fortunate for Asea, since anyone with experience of electric arc furnaces will know that all apparatus connected with them is subjected to extremely severe working conditions. Right from the outset the apparatus manufactured was severely tried out on such work, and on this account Asea designs were in the main completed when the necessity for on-load tap changing with ordinary power transformers arose. The apparatus has been continually improved, chiefly with the intention of making it of more suitable dimensions for inclusion in switchgear layout, and in combination with transformers, while at the same time increasing voltages and outputs have meant the production of new designs. *Fig. 12* shows one of the earliest types constructed for furnace plant, and which at the present time is of historical interest only. The designs illustrated by *figs. 13, 14, and 15* represent intermediate stages, and like the earlier types have the characteristic that the ratio regulators and transformers are erected entirely separate from one another. Connecting leads must be brought out from the transformer and also led into the ratio regulator by means of extra leading through bushings. The many conductors required and the consequent number of bushings represents a weakness, as they increase the difficulty of erection to a great degree, and require considerable space and careful assembly if the installation is to be reliable in service. In contrast to this the modern ratio regulators

constructed by Asea are in general combined with the transformer, and the connecting leads between them are entirely closed in. On the transformer these are brought up to a connection board mounted vertically upon the upper yoke, *fig. 16*, and are connected on this board to threaded contact pieces. The connection boards are placed immediately in front of the openings of the steel pipes which are visible in *figs. 21 and 22* and which unites the transformer tank to the upper part of the ratio regulator, the regulator tank. The cover of this is removable. The assembly of the conductors passing through these pipes can easily be carried out after removing this cover. The conductors are carried from this point to multi-pole leading through bushings, commonly of the condenser type, fixed at the bottom of the regulator tank (*fig. 19*) by means of which the conductors are brought out to the actual ratio adjusting apparatus, which is located in the phase tank below the regulator tank, and which can be raised or lowered. The oil in the unit is divided by the bottom of the regulator tank; one part of the oil being common for the transformer and regulator tank, and in which there are no moving parts, and no contacts, and an entirely separate part surrounding the adjuster apparatus in which all making and breaking of the current takes place. The

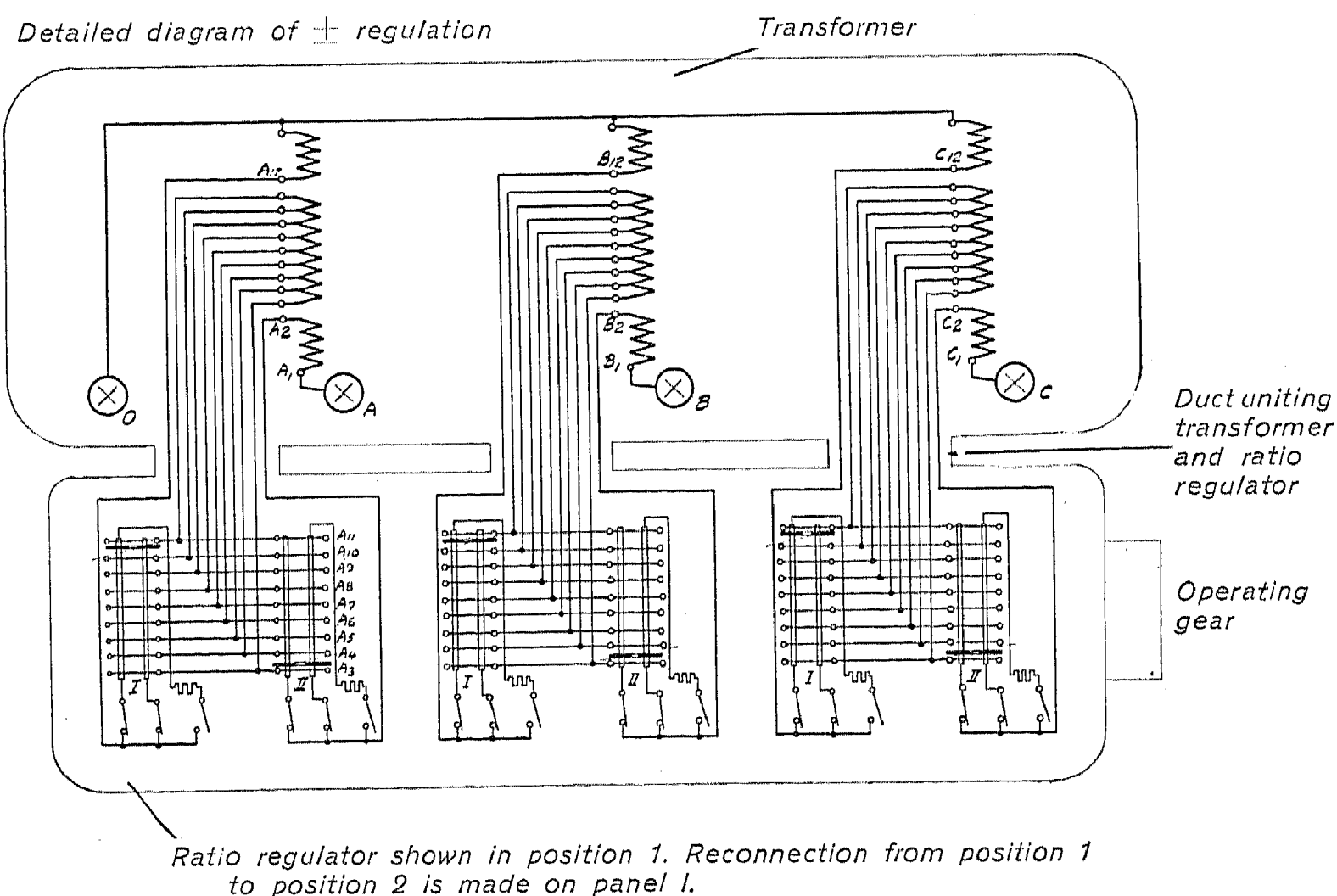


Fig. 18. Diagram of connections for transformer, and ratio regulator, $\pm$ regulation.

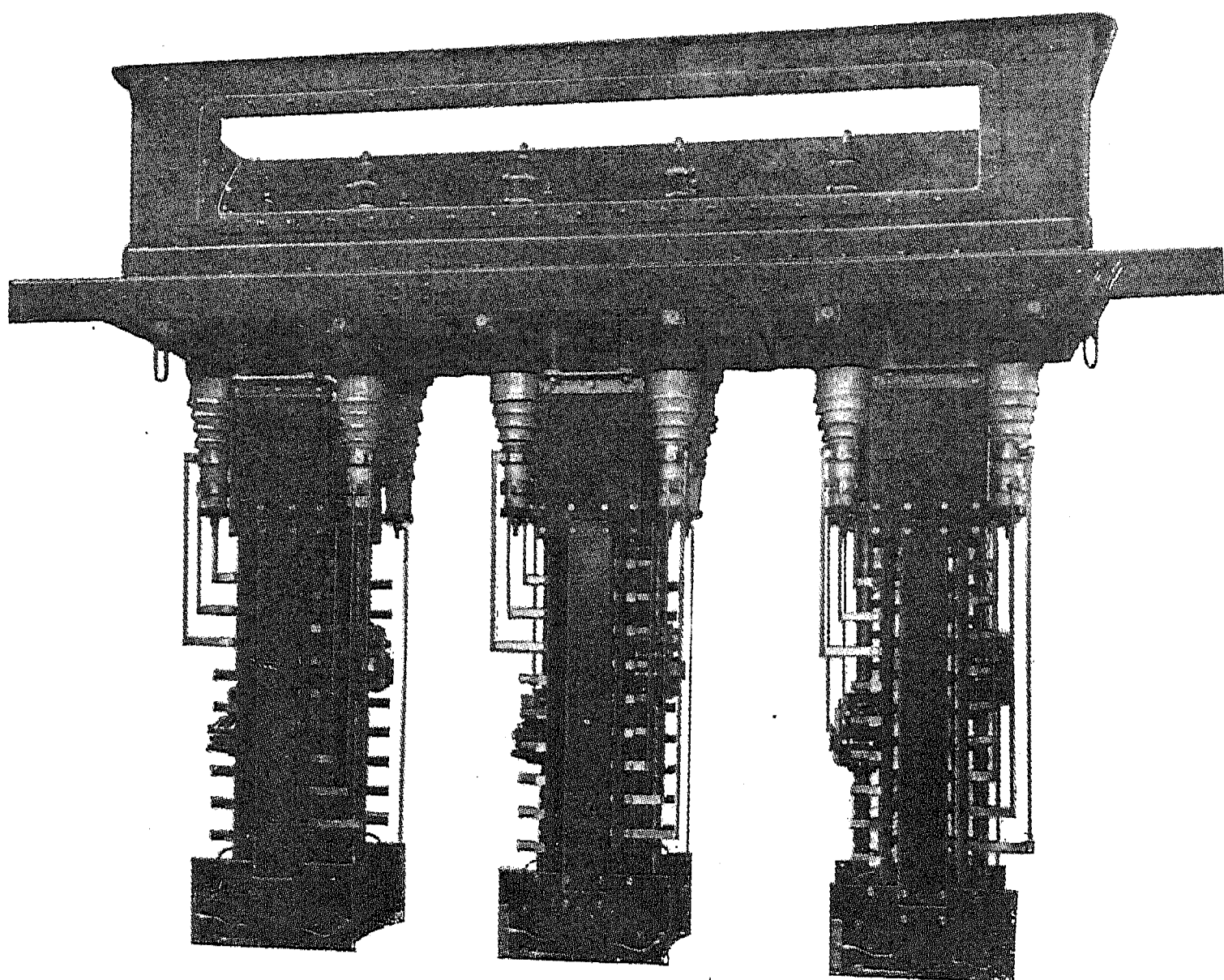


Fig. 19. Three-phase electrically operated on-load ratio regulator designed for combination with 12000 kVA three-phase transformer $50000 \pm 1.5 \pm 3.0 \pm 4.5 \pm 6.0 \pm 7.5 \pm 9.0 \pm 10.5 \pm 12\%$ / 10 600 volts, 50 cycles, in process of erection.

advantages of this arrangement are very obvious: the oil in the transformer is not dirtied by contact breaking and all parts of the contact device are easily accessible for inspection, after lowering the phase tanks by means of the winding gear provided.

The general principals on which modern on-load ratio regulators are constructed can be gathered from the diagrams in *figs. 17 and 18*. A distinction must be made between linear regulation according to *fig. 17* where the ratio regulator has one connection board per phase, the contact device moving from one limiting position to the other, and $\pm$ regulation in accordance with *fig. 18* where the regulator is designed with two connecting boards per phase, over which the contact devices move alternately, each starting from opposite limiting positions and moving alternately towards the middle where they pass one another, and continue to the other limiting position. Clearly all regulation problems could be solved by using either of these arrangements, and from the operating point of view there is no reason to give preference to either system. For this reason the choice of one design or the other depends entirely upon the cost. Generally speaking a $\pm$ regulator is more suitable where the number of voltage steps is large, since the additional cost of the double contact panels and the double mechanism is compensated by the smaller number of contacts necessary in each board, and the smaller number of leading through bushings and connecting leads between the transformer and regulator. If

it is a question of a booster unit, by means of which the voltage is to be regulated on opposite sides of a mean value, the latter design possesses certain advantages, since the booster voltage is changed by the ratio-regulator, so that the absolute value of this voltage and the consequent magnitude of the necessary booster transformer will be half as great as would be required if linear regulation were used.

The main contacts are always arranged in double rows, so that each transformer tapping corresponds to two contact bolts opposite to one another, which during running are parallel connected. This arrangement greatly increases the reliability of operation.

The appearance of the contact apparatus is in accordance with *fig. 20* which shows the double row of contacts and the bus leads between them for the incoming and outgoing conductors. The moving contact bridge working on these contacts is double, in so far as it is in two halves which are connected together but insulated from each other and are operated together by the square threaded lead screw lying in the centre of the apparatus. This screw turns one complete revolution for each operation and the pitch of the screw thread is equal to the distance between two contacts. By means of a special arrangement the contact arm is moved with a zig zag motion, and during the first half turn of the screw the left hand contact does not move, while the right hand contact moves to the new position, after which during the second half turn, the left hand contact moves whilst the right hand contact remains in its new position, so that at the end of the operating period the parallel movement of the whole contact arm has taken place. In order that during change over no current breaking shall take place, and the current in the windings

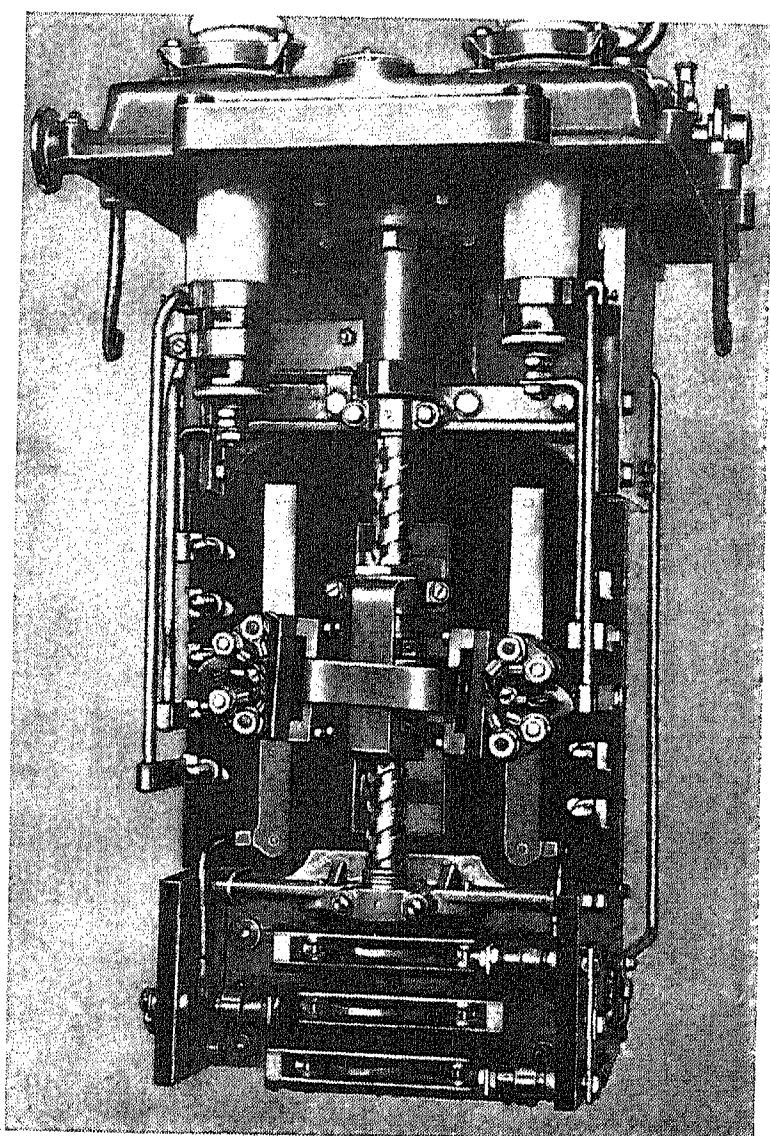


Fig. 20. Contact and breaking device for on-load ratio regulator.

be limited to its normal full-load value an ohmic resistance is provided. This is connected between the bus-leads on the contact panel and is thus normally short circuited. As soon as one side of the contact is broken, the resistance is connected in series, and carries the main current. During the last part of the movement the resistance is short circuited once more. Ohmic resistance for current limiting is made use of on account of cost and space considerations, while at the same time burning of contacts and dirtying of the oil is less than if a reactance were used for the same purpose. With this latter arrangement the breaking might take place at an unfavourable moment when the current and voltage were out of phase. The resistance element is dimensioned very liberally and can carry continuously the whole line current although normally only in circuit for a fraction of a second. No immediate harm would result on this account if the ratio regulator were to stop in a mid position. On the other hand there is no possibility of dissipating the large amount of heat generated if the resistance should

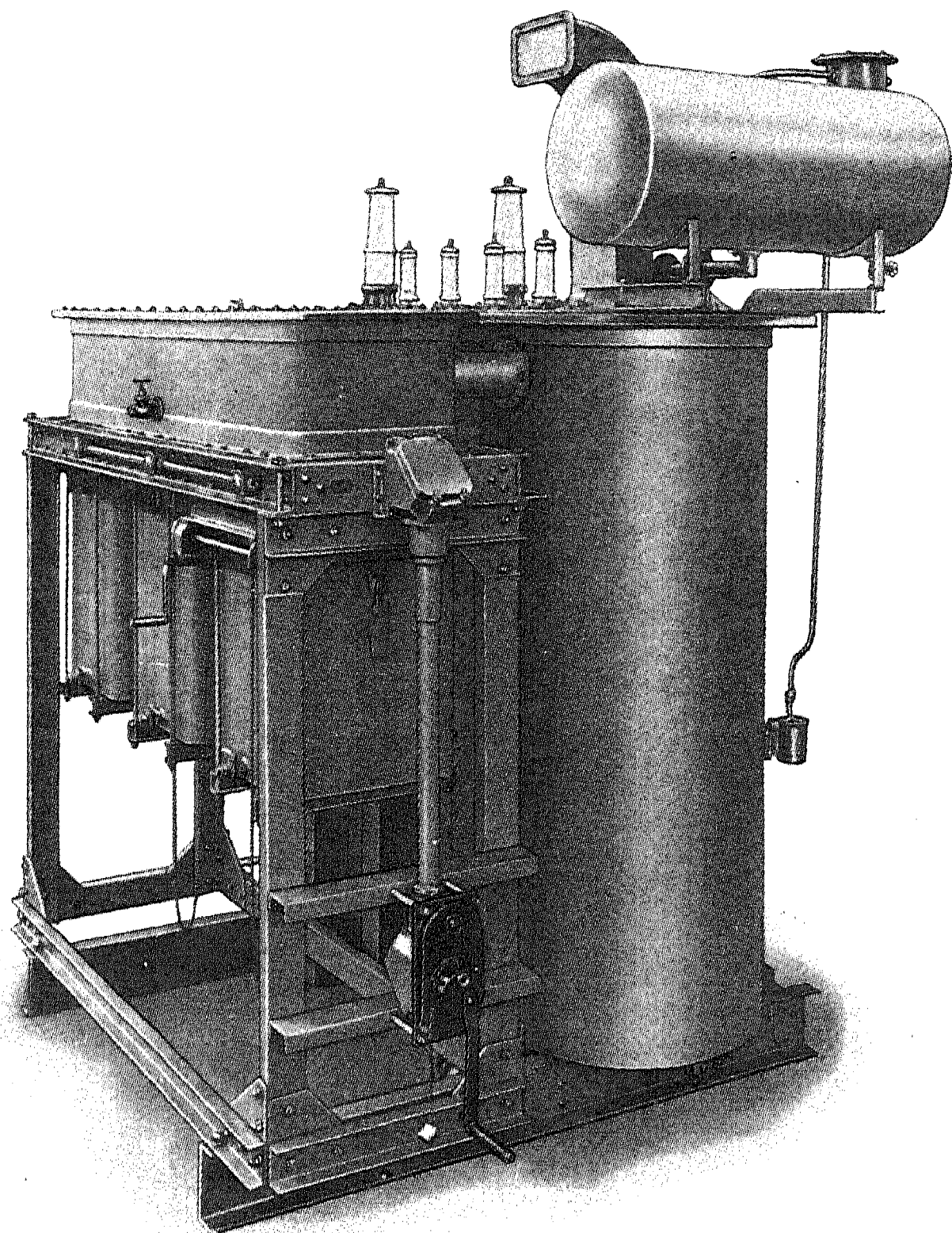


Fig. 22. 3000 kVA three-phase transformer combined with hand operated on-load ratio regulator 52 500/23 000—22 000—21 000—20 000—19 000 volts, 50 cycles.

be left continually in circuit, so that the temperature of the oil increases very rapidly if the ratio regulator is left in an intermediate position. The occurrence of this must accordingly be provided against, and following safeguards are introduced. The motor which drives the operating gear is provided with a flywheel of such size that the movement of the contacts will be fully completed even if the operating current supply should be broken. In addition the operating mechanism cannot be connected to the operating shaft before the flywheel has reached full speed, so that there can be no movement of the contacts if the supply should fail before this speed has been reached. The winding coupler is also provided with two independent signalling arrangements. One of these is actuated directly by a movement of the operating gear, and gives an indication during the whole time that regulation is in progress, while the other is actuated by a thermo contact immersed in the oil, and gives a signal if the temperature should increase beyond a certain predetermined value.

In the case of apparatus designed for low currents all breaking takes place directly on the main contacts. Ratio regulators for high current are, however, furnished with a central breaking

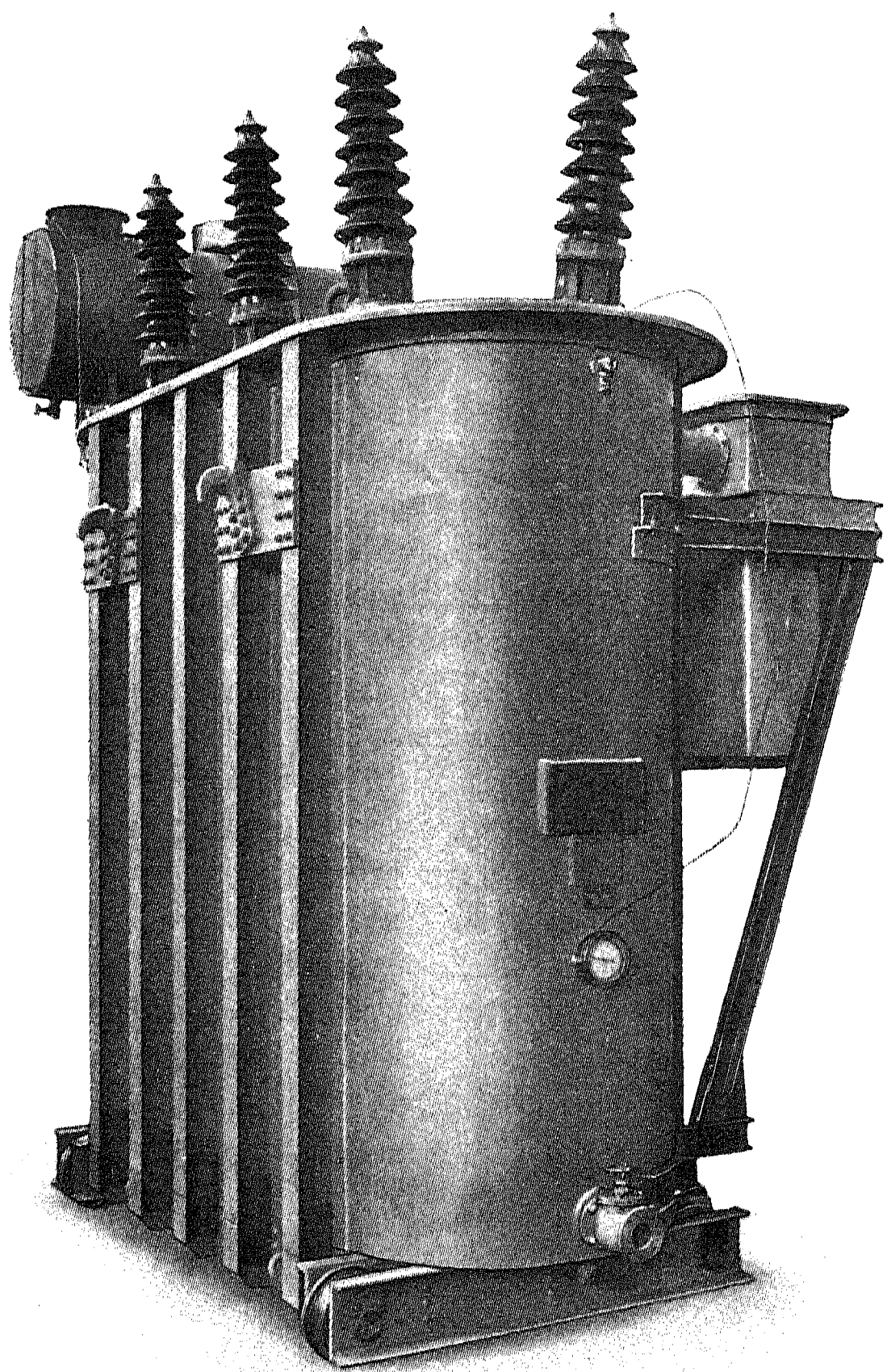


Fig. 21. 15000 kVA forced oil cooled three-phase transformer combined with motor operated on-load ratio regulator 105 000/22 300 $\pm 2 \pm 4 \pm 6 \pm 8 \pm 10$ % volt, 50 cycles, 5250

device where all the current breaks occur, so that the main contacts do not carry current when in operation. The diagrams *figs. 17 and 18* indicate such a central breaking device, and the same thing is also shown in *fig. 20*. The device consists of the three pairs of button contacts visible at the bottom of *fig. 20* and which are operated by cams on the same shaft as that which operates the main contacts. Both main and auxiliary contacts are easily interchangeable after lowering the phase tank.

Assembly is carried out in different ways depending on the relative sizes of transformer and regulator. In the case of all large transformer units the regulator can be hung from the side of the transformer. *Fig. 21* and the illustration of the front page show examples of this arrangement for a forced oil cooled and self cooled transformer respectively. For smaller transformer units ratio regulator and transformer are erected upon a common base in accordance with *fig. 22* while for the smallest units where the transformer is often of smaller dimensions than the regulator the equipment is constructed with the regulator and transformer as one unit i.e. the ratio regulator tank and the transformer tank are welded together, and provided with a common cover (*fig. 23*). The connections between the two in such a case do not require any ducts, but are taken direct from the windings to leading through bushings in the bottom of the regulator tank. This arrangement cannot be adapted to large units, since the combined breadth would be so great that the unit could not be brought within the ordinary loading gauge for transport purposes.

Very often the units are installed at various suitable points on a network exclusively with the view to regulating the voltage or dividing the reactive power. In such cases the transformer may with advantage be auto-connected and is thereby relatively small in relation to the size of the ratio regulator, in which case the last arrangement described above can be used (*fig. 23*). Upon the cover there are only three leading through bushings for the incoming line and three for the outgoing line.

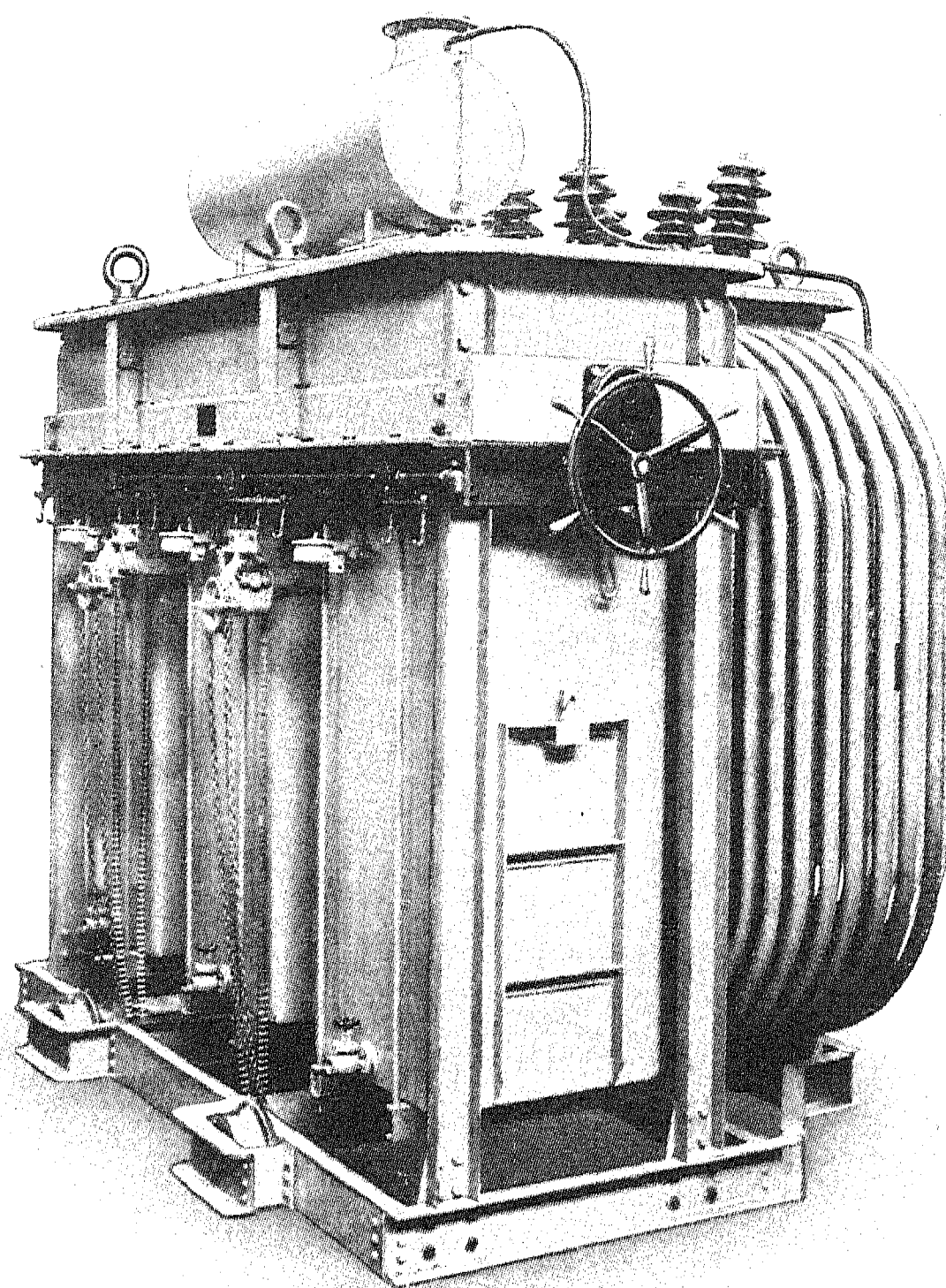


Fig. 23. Voltage regulating unit for passing 3600 kVA, consisting of three-phase auto connected transformer, and hand operated on-load ratio regulator. Range of regulation 35.4—34.4—33.4—32.4—31.4—30.4—29.4—28.4—27.4—26.4/33.4 kV, 50 cycles.

Ratio regulators are constructed at present for direct connection to lines having a maximum main voltage of 77 kV and for a maximum transmitted current of 100 amps. If these limits are exceeded intermediate transformers can usually be employed with advantage. In accordance with standard arrangements the number of steps provided is up to 17, but by taking special precautions this range may be further extended in certain cases. Ratio regulators are sometimes manufactured for hand operation, but in general are motor operated, the operating gear being set in motion by push buttons or by means of a relay equipment automatically actuated so as to secure a constant voltage or a voltage increasing with the load.

UNDERGROUND TRANSFORMER SUBSTATIONS.

BY F. HEIMER & N. FRENNING.

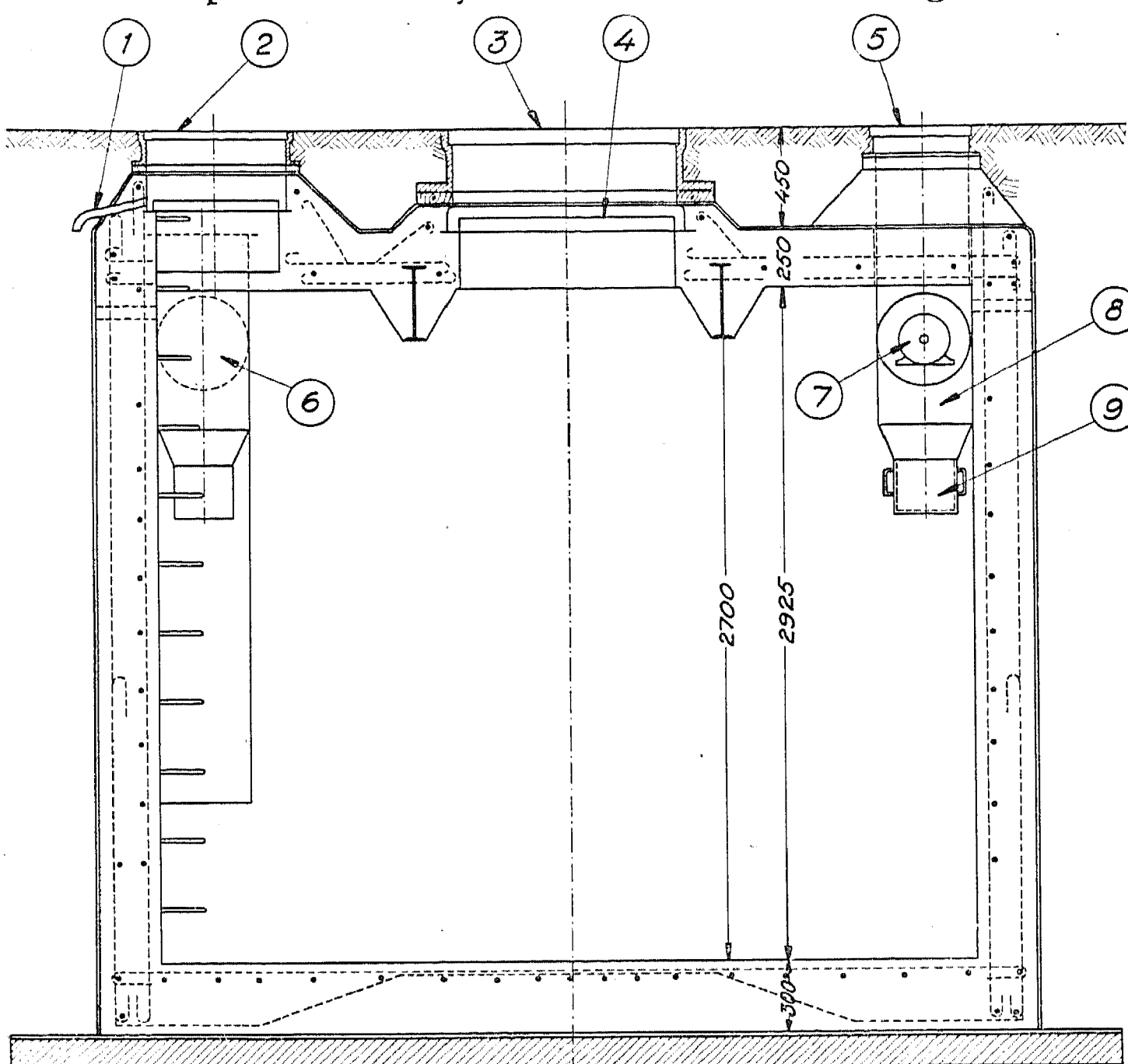
During the period 1927–1930 the Westeras Municipal Electricity Works, Sweden, changed

depending on development. For this purpose 15 transformer Substations are to be built with H.T. and L.T. cables etc. for a total maximum load of 3000 kW (3 times the present D.C. load). As a commencement permission was obtained from the Municipal Authorities in August 1930 to proceed with the work on one of the most central sections of the town. The first development includes a high tension switchboard in the Electricity Works with two outgoing groups of duplicate cables (each $3 \times 50 \text{ mm}^2$) and two transformer Substations each of $2 \times 250 \text{ kVA}$. At the same time a further Substation has been built, but not equipped electrically for the time being.

As soon as plans were considered it was found that it would be difficult if not impossible to obtain the necessary sites for placing the Substations above ground.

Land in the centre of the town is so expensive that high rentals would have had to be paid for building sites. It was accordingly decided to build both the stations underground. The general appearance of these Substations will be clear from *fig. 1*.

The sub soil in Westeras consists for



1. Rain water drain. 2. Entrance man-hole. 3. Upper grating. 4. Tightening cover.
5. Ventilating duct. 6. Cold air duct. 7. Fan. 8. Collecting well.
9. Removable rubbish bin.

Fig. 1. Section through underground transformer substation.

over some of the outlying residential districts of the town to A.C. The intention of this was to avoid the installation of additional converting machinery in the Electricity Works, and also if possible to reduce the D.C. load sufficiently to obtain an adequate margin of reserve. By the Autumn of 1929, however, the D.C. load had increased to such an unexpected extent as to make it apparent that the above mentioned change-over to A.C. would not be sufficient, and that other means would have to be adopted. In choosing between the reinforcement of the D.C. distribution system, with a simultaneous extension of the converting machinery and the introduction of A.C. in the centre of the town, a careful investigation from all sides indicated that the A.C. scheme was to be preferred, and would be likely to be advantageous in the long run.

In accordance with plans which have been prepared the change-over of the centre of the town to A.C. will be carried out successively in a period of 20–30 years

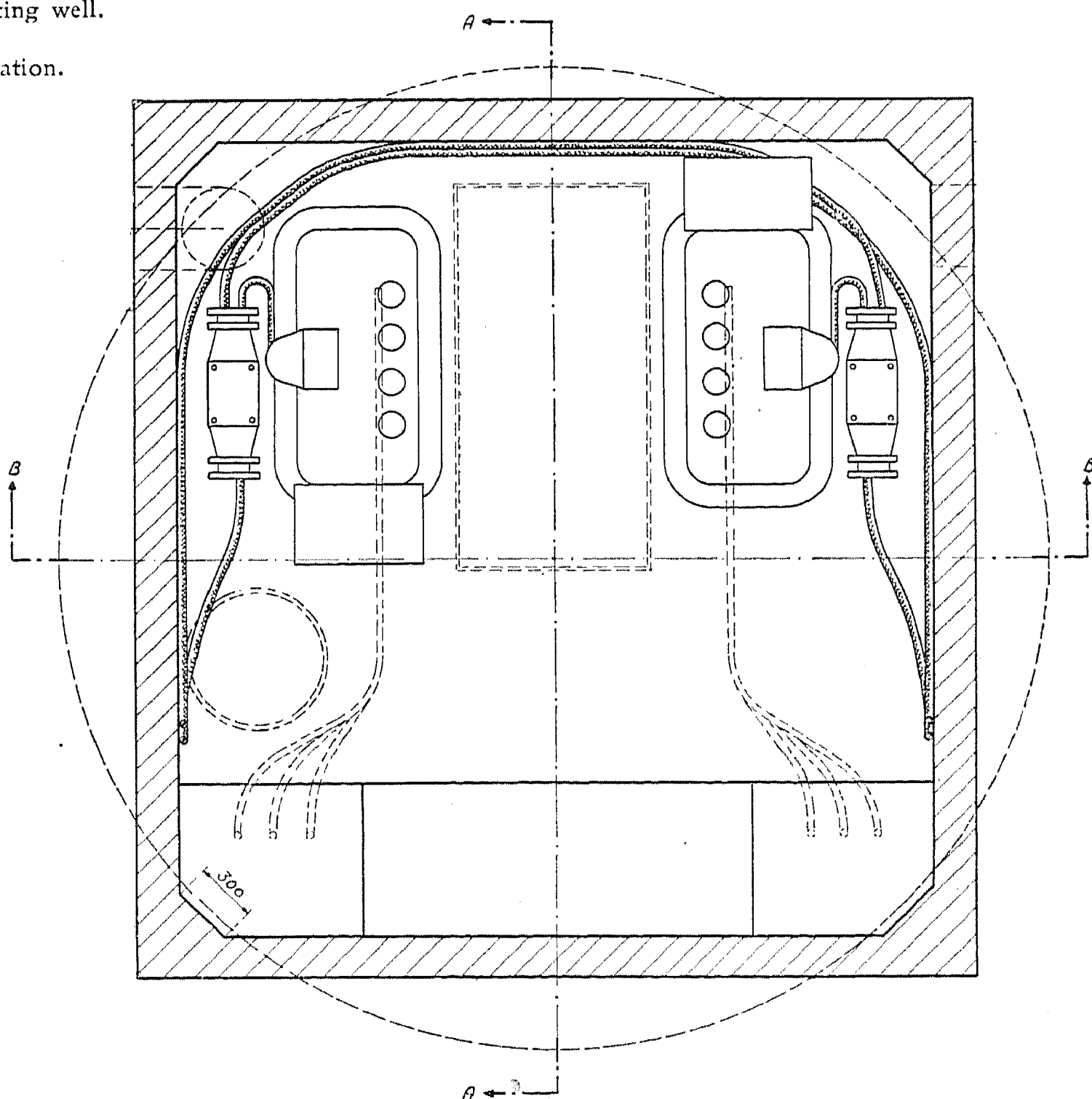


Fig. 2. Plan of underground transformer station.

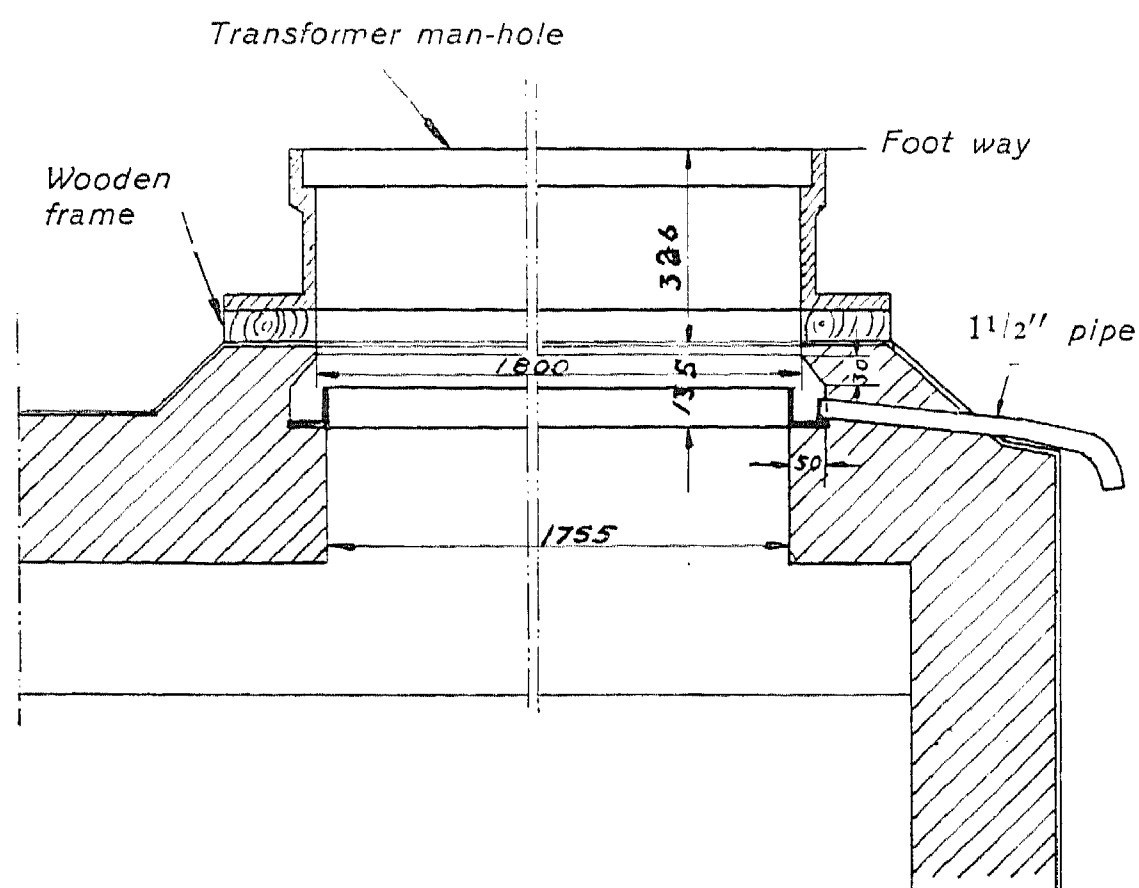


Fig. 3. Section of transformer man-hole.

the most part of soft clay at a depth of from 1–2 metres below the ground level, and which is impervious to surface water. For draining the building and also for providing drainage during the constructional period a 2" galvanised pipe about 60 ft. in length was driven through the clay to gravel lying beneath. The pipe was furnished with drainage holes in the side. To prove that the pipe functioned properly as a drain, water was poured into the excavation, and it was found that water in the pipe immediately fell to the level of lake Mälaren. The underground chamber is constructed of concrete, the internal dimensions being: length 3700 mm, width 3500 mm and height to the roof 2925 mm. The floor lies 3625 mm under the pavement level. The thickness of the walls and roof is 250 mm, and the thickness of the floor 360 mm including protective concrete slabs. 15 mm round iron has been introduced for reinforcement purposes.

In the foot way above the Substation several cast iron manholes and gratings have been arranged. These include a large opening for the entrance of transformers of sizes up to 300 kVA, a smaller man-hole for inspection, a vertical air duct with grating for the entry of cooling air, and a similar opening for the exit of heated air. These last have an internal diameter of 400 mm. Below the two cast iron gratings are placed inner cover grouted into the concrete and so arranged that any moisture entering from above is collected in a gutter furnished with an outlet pipe which is carried through the substation wall. Rubbish and dirt which may enter through the hot and cold air ducts from the pavement above is collected in a bin *fig. 4* which is placed under these ducts inside the Substation. This bin can be easily removed and emptied. The ventilating air enters and leaves through T pieces in the ducts. In the T piece of the hot air duct is placed a propeller fan for

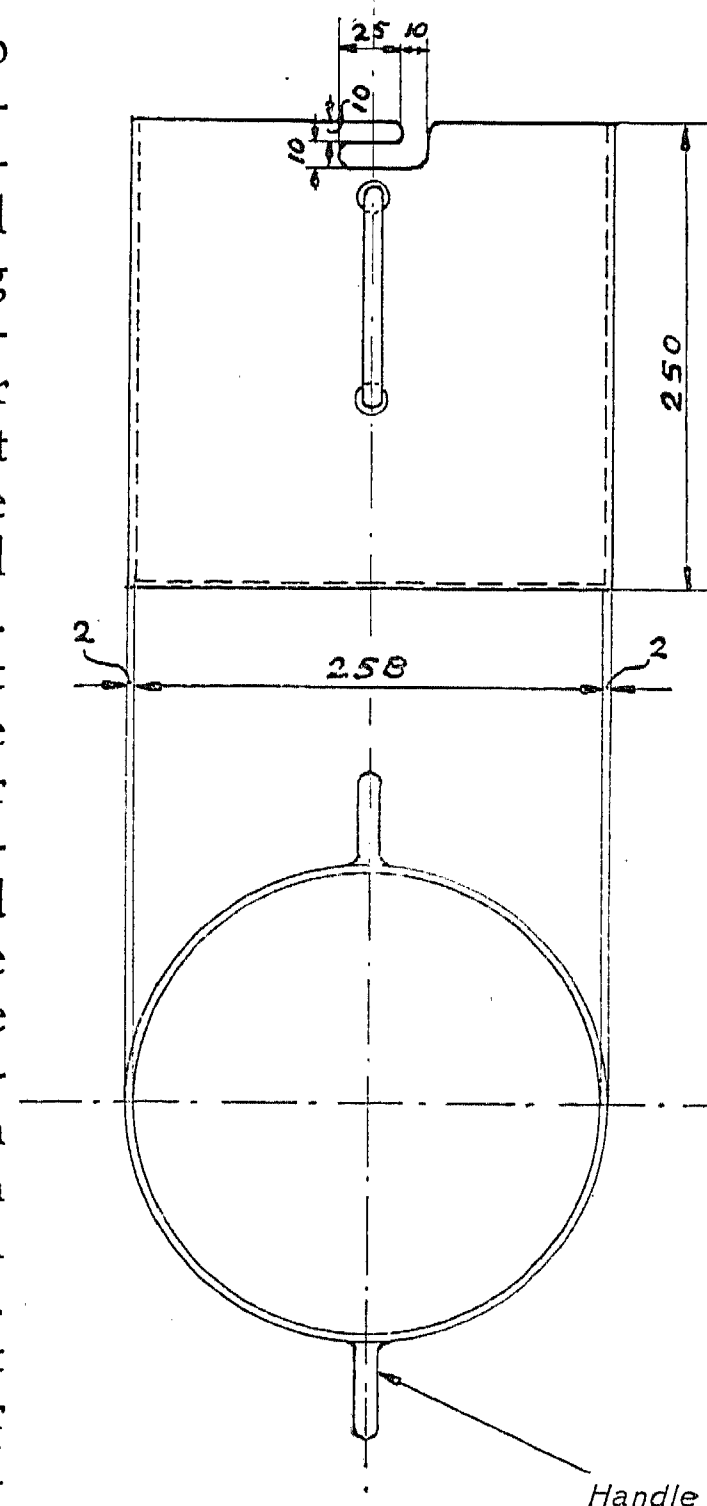


Fig. 4. Collecting bin for rubbish and water.

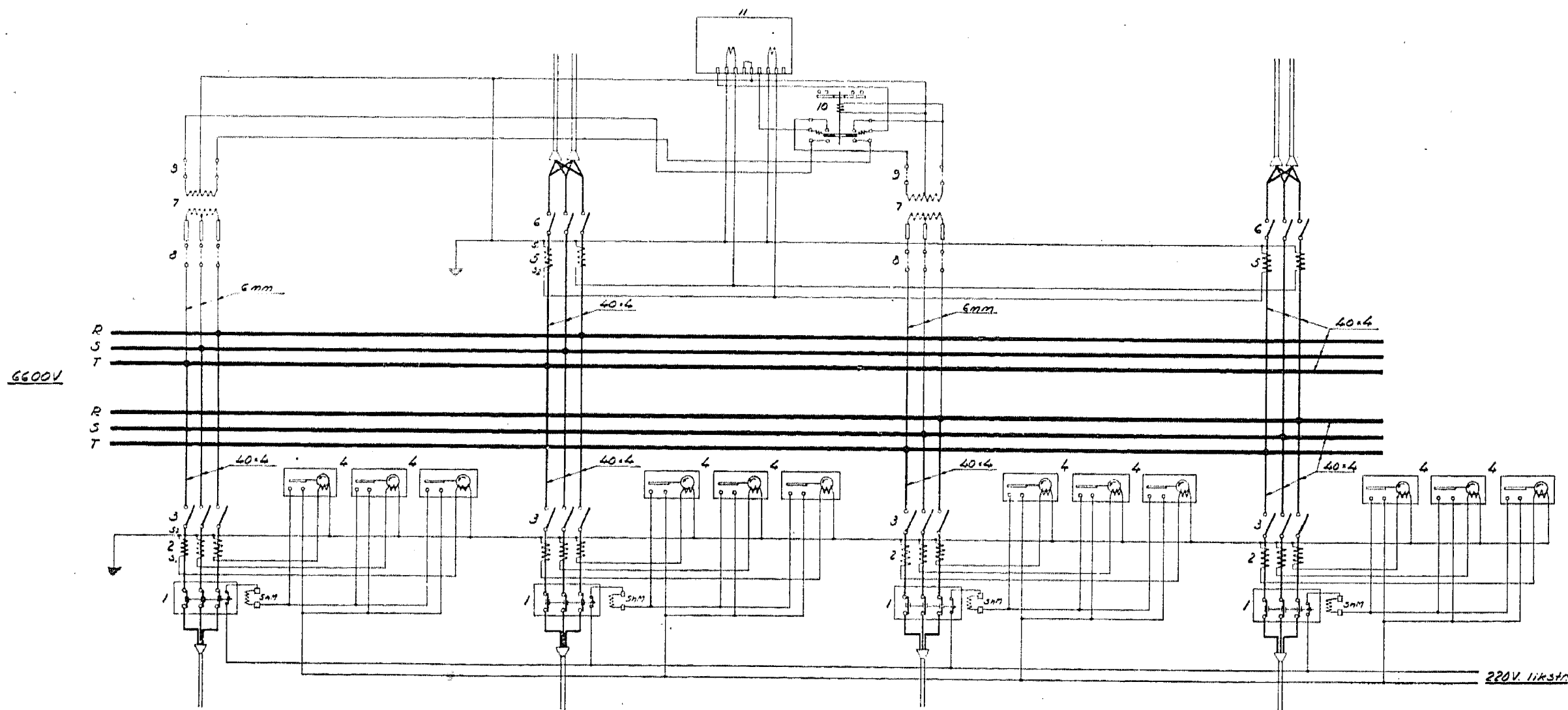


Fig. 5. Diagram of connections for double supply system.

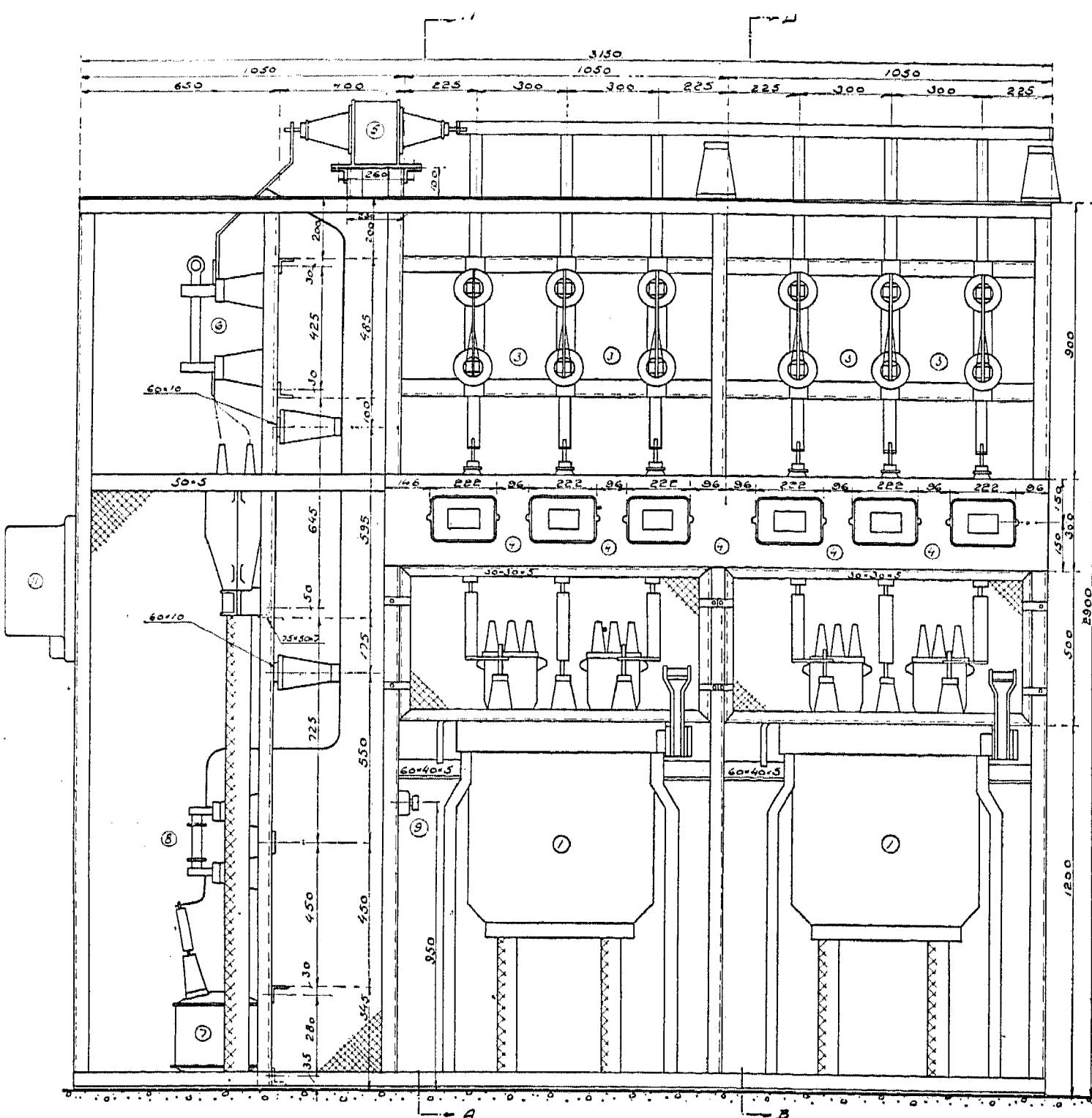


Fig. 6. Switchgear in Electricity Works.

30 m³ per minute, which provides sufficient air to maintain a temperature rise of about 20°C in the case of the 300 kVA transformer fully loaded.

Each Substation is equipped with two transformers of 250 kVA, 6400±3%/230 volts operating in parallel on the L.T. side. Each trans-

former is connected to its own 6 kV cable in the duplicate cable system. No H.T. switchgear is provided. The H.T. switchgear for all transformer Substations is located in the Electricity Works, and provision has been made (in accordance with the plans) for 15 stations. The switchgear is arranged with two electrically separate systems A and B (fig. 5). This system has been chosen in order to provide adequate stand by facilities as regards H.T. switchgear, H.T. cables and transformers. This arrangement was naturally adopted so as to protect consumers as far as possible against any failure in the supply.

From the Electricity Works duplicate cables run in two branches to 7 and 8 transformer Substations respectively. For these cables oil circuit breakers are provided in the Works mounted in open cubicles of steel construction and provided with overload protection (see fig. 6).

For the secondary side of the transformers oil circuit breakers are provided with directional differential protection (see fig. 7). In the case of a fault on the H.T. side e.g. on system A, current from system B can only be fed into the fault through the secondary side of the A system. Directional differential protection then trips the oil breaker on the secondary side of system A, the primary side of the A system also being released.

System B then carries the whole of the load of the Substation in question.

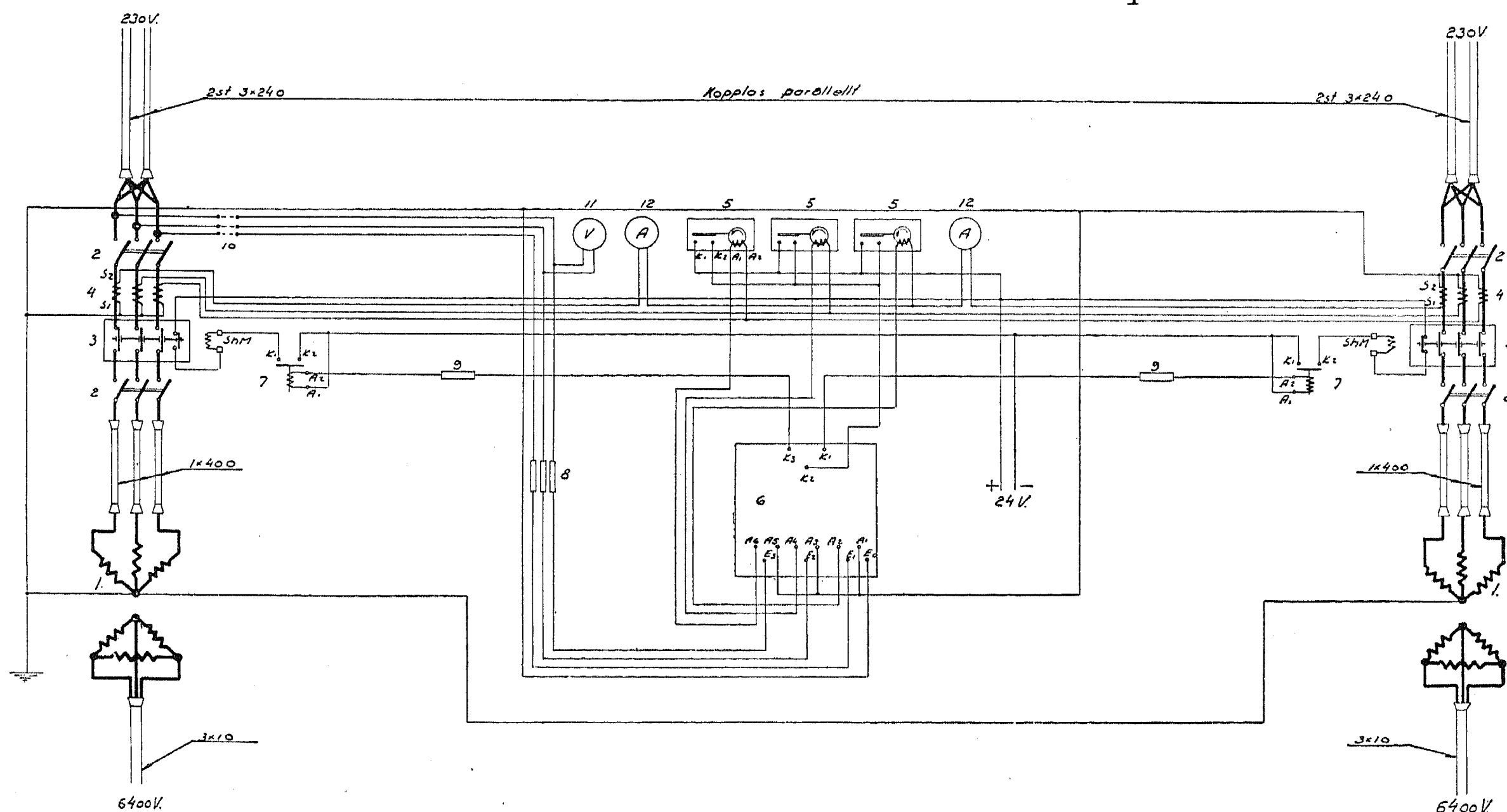


Fig. 7. Diagram of connections for secondary side of transformers.

The equipment on both systems is dimensioned capable of dealing with the whole load of one Substation.

This division into two separate systems provides other advantages, e.g. makes possible the inspection of transformers, apparatus and cables in one system, while the other system is in service.

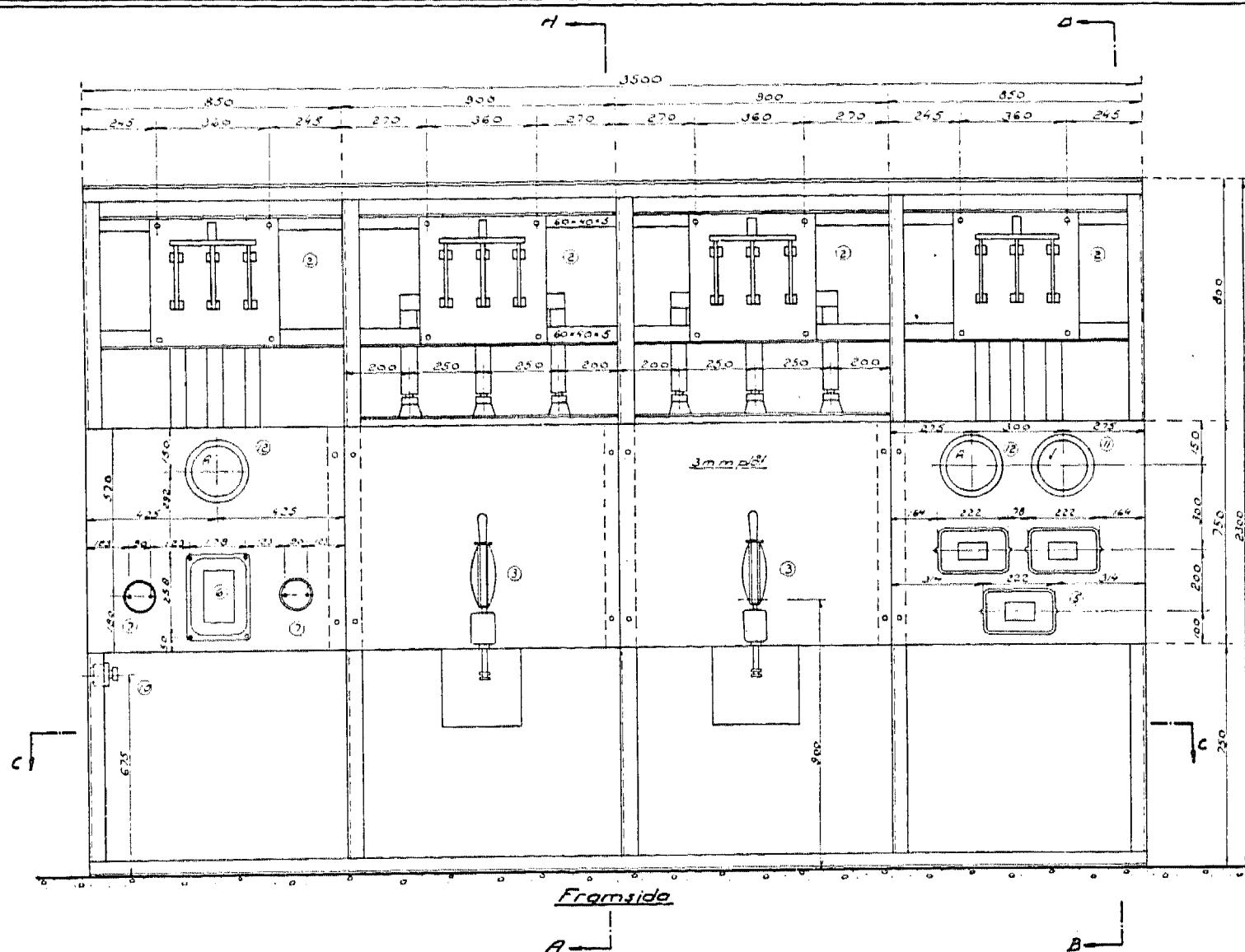


Fig. 8. Switchgear for secondary side of transformers.

The switchgear for the secondary sides of the transformers is as shown by *fig. 8*.

From the L.T. board run 2—4 parallel cables to a feeder pillar mounted above ground in the vicinity, and are there branched through fuses of 300 amps. maximum, the cartridges of which can be handled while alive.